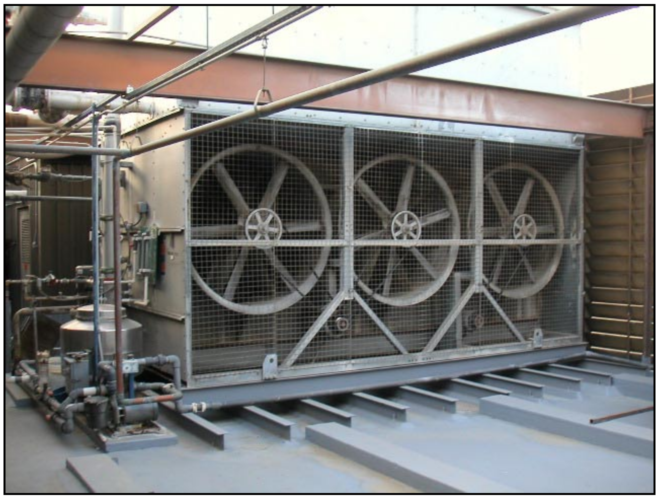
DATA CENTER ENERGY BENCHMARKING CASE STUDY

FEBRUARY 2003



DATA CENTER FACILITY 4

Sponsored by

Lawrence Berkeley National Laboratory
Environmental Energy Technologies Division

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Acknowledgements

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APPENDICES

I. Executive Summary

Rumsey Engineers and the Lawrence Berkeley National Laboratory (LBNL) have teamed up to conduct an energy study as part of LBNL's data center energy benchmarking efforts. This study is intended to provide measured information on energy and power use in data centers, and to help designers make better decisions about the design and construction of data centers in the near future. This report describes the outcomes of energy benchmarking in two data centers in Fresno, California, and the observations on potential opportunities in efficiency improvement. Measurements were conducted on-site from November 12 to 15, 2002, with the particular aim of determining the end-use of electricity power by infrastructures, computer equipment, and other components. he identity of data center owner and/or end-user is kept anonymous. The facility that houses both data centers is referred as "Data Center Facility 4" throughout this report.

OBSERVATIONS AND RECOMMENDATIONS FOR ENERGY EFFICIENCY IMPROVEMENT

There are many opportunities for saving energy in this facility. The primary sources of inefficiency are the uninterruptible power supply (UPS), the Trane reciprocating chiller plant serving Data Center 4.1, and the computer room air-conditioning (CRAC) unit fans. This report concludes with ten recommendations that address these issues, four of which agree with those made in a May 2001 report presented to this facility through a previous Federal Energy Management Program (FEMP) study.[1]

[1] "Assessment of Load and Energy Reduction Techniques (ALERT), Final Report" by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Federal Energy Management Program. Date of site visit, May 22-23, 2001.

II. Definitions

Data Center Floor Space
Gross footprint area of controlled data center space devoted to company/customer equipment. Includes aisles, caged space, cooling units, electrical panels, fire suppression equipment, and other support equipment. This gross floor space is what is typically used by facility engineers in calculating a computer load density (W/sf).[2]

Data Center Server/Computer Load
Electrical power devoted to equipment on the Data Center Floor. Typically the power measured upstream of power distribution units or panels. Includes servers, switches, routers, storage equipment, monitors, and other equipment.

Critical Load
Electrical load of equipment that must keep running in the event of a power failure. Such loads are typically served by an Uninterruptible Power Supply (UPS), which uses a bank of batteries to support the load when the normal source of power fails. The batteries can support the load for only a short period. In some facilities the equipment is shut down gracefully and turned off until normal power returns. In other facilities a backup generator, typically diesel-powered, comes on-line and provides power for a longer period of time.

Data Center Cooling Power
Electrical power used to cooling equipment for the Data Center Floor Space.

Computer Equipment Occupancy
This is based on an estimate on how physically loaded the data centers are by computer and equipment footprints.

Measured Computer /Server Load Density
Ratio of actual measured Data Center Computer/Server Load in Watts (W) to the gross area (ft^2 or sf) of Data Center Floor Space. Includes vacant space in floor area.

Projected Computer /Server Load Density
Ratio of projected Data Center Computer/Server Load in Watts (W) to square foot area (ft^2 or sf) of the Data Center Floor Space if the Data Center Floor Space were fully

[2] Users look at watts per square foot in a different way. With an entire room full of communication and computer equipment, they are not so much concerned with the power density associated with a specific footprint or floor tile, but with larger areas and perhaps even the entire room. Facilities engineers typically take the actual UPS power output consumed by computer hardware and communication equipment in the room being studied (but not including air handlers, lights, etc.) and divide it by the gross floor space in the room. The gross space of a room will typically include a lot of areas not consuming UPS power such as access aisles, white areas where no computer equipment is installed yet, and space for site infrastructure equipment like Power Distribution Units (PDU) and air handlers. The resulting gross watts per square foot (watt/ft2-gross) or gross watts per square meter (watt/m2-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting.

	Floor Space if the Data Center Floor Space were fully occupied. The Projected Data Center Computer/Server Load Density is usually higher than actual measured density and can be calculated by multiplying the reciprocal of actual computer equipment occupancy.
Computer/Server Load Density per Rack Footprint	Measured Data Center Computer/Server Load in Watts (W) divided by the total floor area that the racks or equivalents occupy, or the rack "footprint".
Cooling Load Density	The amount of cooling (tons) supplied to a given floor space (Ton/ft^2 or sf)
Cooling Effectiveness Index	Ratio of electrical power devoted to cooling data center space to the electrical power used by computer and equipment. A lower number likely corresponds to more effective cooling.

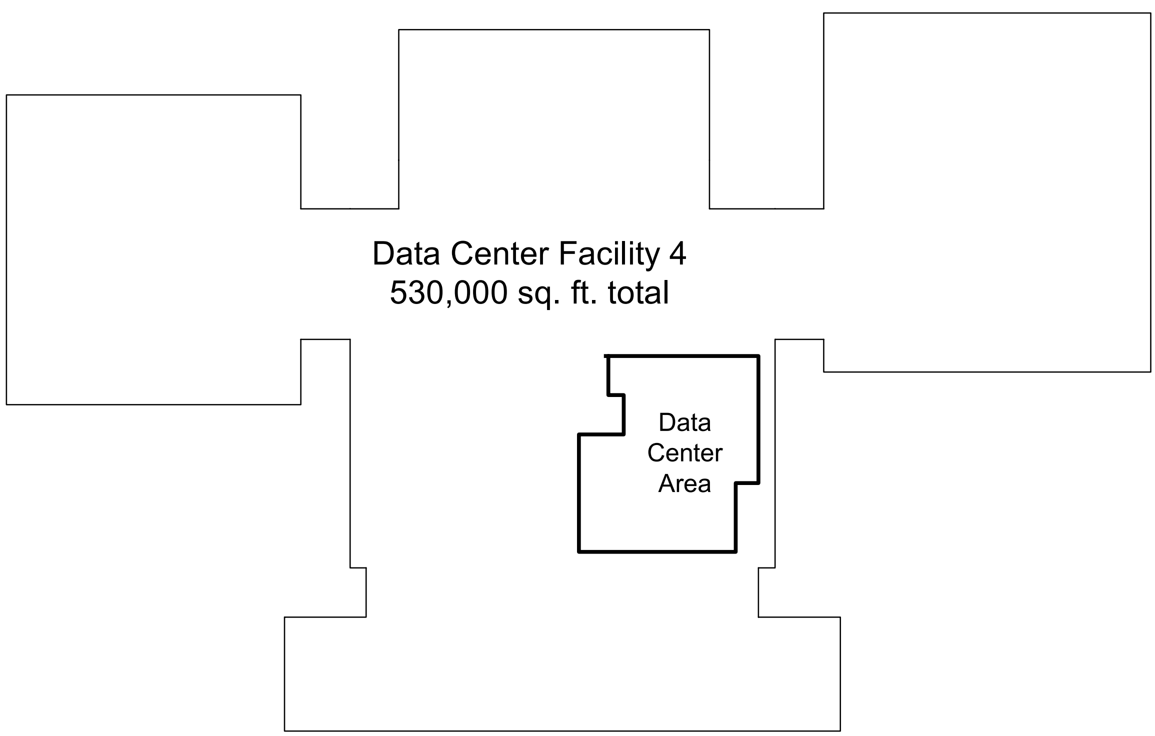
III. Site Overview

On their web site (http://datacenters.lbl.gov/What.html), LBNL defines "data center" as follows:

> "We define a data center as a special facility that performs one or more of the following functions:
>
> - Store, manage, process, and exchange digital data and information;
> - Provide application services or management for various data processing, such as web hosting Internet, intranet, telecommunication, and information technology.
>
> We do not consider spaces that primarily house office computers including individual servers associated with work stations as data centers."

Data Center Facility 4 is housed in a single building. In previous decades, according to staff, the data center area contained mostly large, mainframe style computers. This area represented about 7% of the total floor area of the facility. (See Figure 1.) The data center area was cooled independently of the rest of the building.

Figure 1. Facility Site Plan



Today, not all of the original data center area is used for data center purposes. Refer to Figure 3 for a simplified floor plan. Rooms 1 and 5, and the Network Room, now contain modern servers, storage drives, printers, and stand-alone PCs. Rooms 1 and 5 are sparsely occupied by current data center standards (Fig. 2), and contain a wider variety of equipment than is seen in a typical electronic commerce "server farm", for example. There are relatively few rack-style servers.

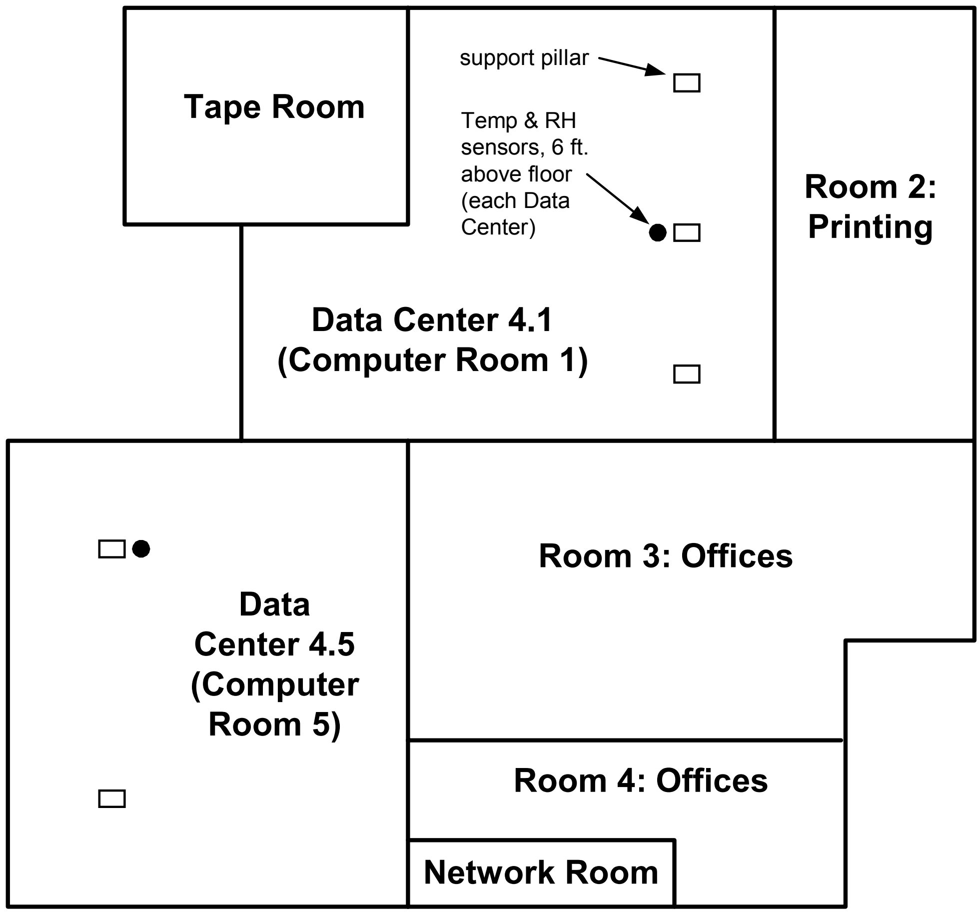
Rooms 1 and 5 also have more than one use. Part of Room 1 is used for storage. Room 5 contains three desks that are regularly occupied by staff. These three desk stations aside, the measurement team observed relatively little foot traffic in Rooms 1 and 5.

Figure 2. Example of Sparse Occupancy

Rooms 3 and 4 have been converted to office space. The Tape Room, Print Room (Room 2), and the Network Room continue to support data center operations, but are not included in this study. Rooms 3 and 4 now receive cooling from the same chilled water plant that serves the remainder of the building. The remaining rooms – 1, 2, 5, the Network Room and the Tape Room – continue to receive cooling from independent systems.

Rooms 1 and 5 are cooled in completely different manners, as described below. These two rooms are the focus of this report, and are hereafter referred to as Data Center 4.1 and Data Center 4.5. They are 8,900 square feet (sf), and 8,560 sf, respectively; this represents about 3% of the total building area.

Figure 3. Data Center Floor Plan



Data Centers 1 and 5 are cooled by dedicated Computer Room Air Conditioning (CRAC) units. The CRAC units are the only source of cooling for these two rooms. Outside air is provided indirectly by infiltration from adjacent rooms. The CRAC units in Data Center 4.1 use chilled water, normally provided by a dedicated plant comprised of four 100-ton reciprocating Trane water-cooled chillers. The CRAC units in Data Center 4.5 are split systems, with rooftop air-cooled condenser units.

Both data centers have raised floors, consisting of 2-foot by 2-foot tiles approximately 1 foot above the underlying slab. Most of the tiles are solid, but approximately 10% of them are perforated and distributed across the floor area. The CRAC units supply air to the underfloor space. Air rises through perforated tiles, and returns through grills located in the top of the CRAC units. All CRAC units are capable of humidity control.

A separate chilled water plant, consisting of two 750-ton Trane centrifugal chillers and a 1000-ton York centrifugal chiller, serves the rest of the building. This system was not monitored for this study.

IV. Energy Use

UNINTERRUPTIBLE POWER SUPPLY

A 450 kW Emerson Accupower model AP56 uninterruptible power supply (UPS) provides power to the critical loads in data center rooms 1 and 5, as well as the Print Room and Network Room. The UPS converts alternating current to direct current and charges a battery bank. Direct current from the batteries is converted back to alternating current and is fed to the data centers. In the event of a power outage the battery bank supplies power for about 30 minutes, which is long enough to permit a graceful shutdown of the critical computer loads. The UPS nameplate full-load efficiency is 92%.

The power supplied to and from the UPS was recorded for one day to determine the total critical computer load and the loss in the UPS itself.

Table 1. UPS Electrical Measurements

	Electrical Use[3]	Units
UPS Input	127.0	kW
UPS Output	99.8	kW
UPS Loss	27.3	kW
UPS Efficiency	78.5	%

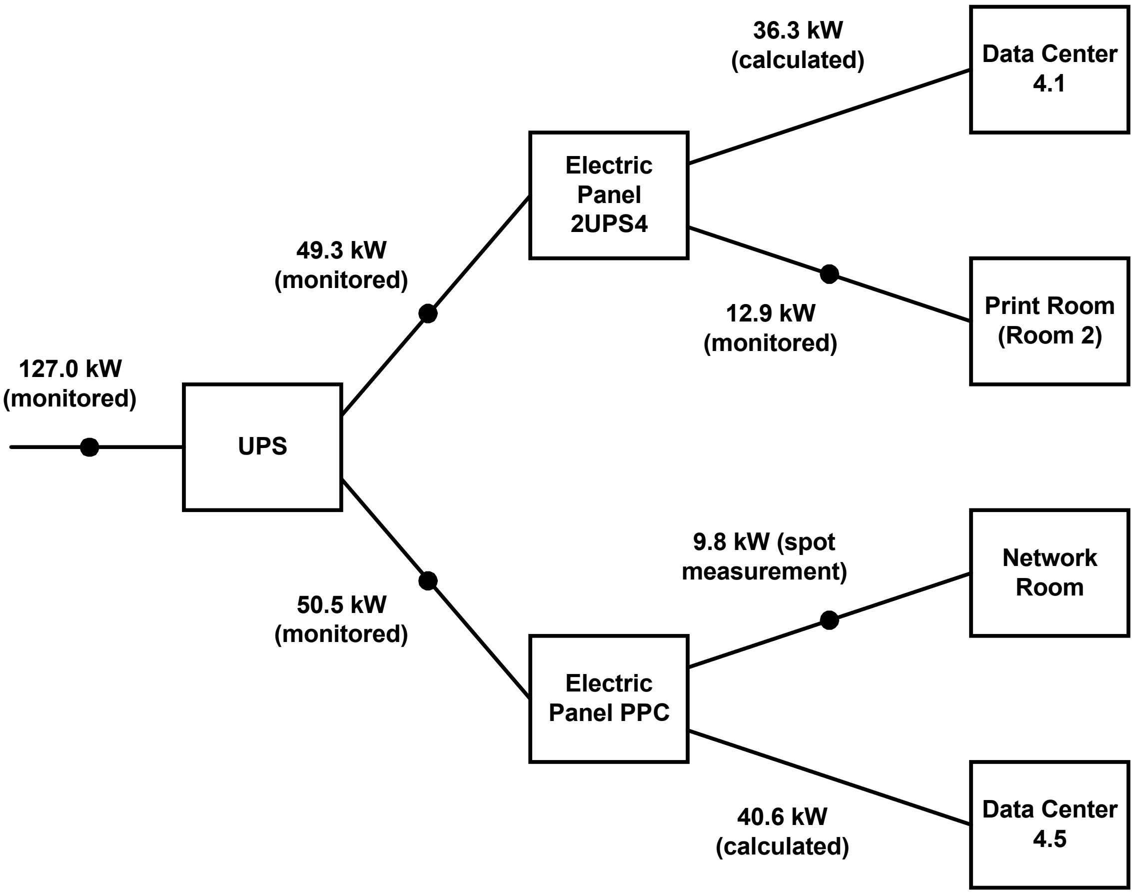
Figure 4. UPS

The measurements show that the UPS is operating well below its nominal capacity and its claimed efficiency. Refer to Appendix A for graphs of the recorded data.

The electric panels serving the data centers are wired in such a way that it was easier to measure the total power of rooms 2 and 4, and obtain the power of data center rooms 1 (Data Center 4.1) and 5 (Data Center 4.5) by subtraction (Figure 5).

[3] Average of 1-minute measurements taken during 11/14/02 - 11/15/02. Unless otherwise indicated, all readings of electric power in this report were made with a Summit Technology PowerSight PS3000 with 1000-amp clamp-on sensors.

Figure 5. Electrical Measurement Points



DATA CENTER 4.1: DATA EQUIPMENT

Data Center 4.1's computer equipment falls into to two categories. All machines that must not immediately lose power in the event of a utility outage are collectively termed the "critical load". This equipment includes servers and their associated terminals (consisting of a monitor and keyboard), printers, and tape drives. This critical load is powered by the UPS. The total critical load was measured directly at two points immediately downstream of the UPS (Figure 5).

The remainder of the equipment (all of it PCs) is termed "non-critical". Rather than attempt to measure the non-critical load directly, an inventory of the non-critical equipment was made and the load was estimated. For details, see Appendix B. As shown in Table 2, the non-critical load is relatively small. In the summaries that follow, the total estimated load – 36.7 kW – is used in all calculations and the distinction between critical and non-critical is no longer made.

Table 2. Data Equipment Loads

	Electrical Use	Units
Critical	36.3[4]	kW
Non-Critical	0.4	kW

Figure 6. Servers in Data Center 4.1

DATA CENTER 4.1: COOLING SYSTEM

CHILLED WATER PLANT

Under normal operating conditions, the CRAC units in Data Center 4.1 receive chilled water from a chilled water plant that is dedicated to the data center area. The chiller plant contains four 100-ton reciprocating Trane water-cooled chillers. Only one of the four chillers (Chiller 3) was operating during the monitored period.

[4] Average of 1-minute measurements taken 8:53 to 9:24 on 11/15/02.

The facility is equipped with a computer system for monitoring the function of both chilled water plants, but it is not capable of automatic control of the dedicated Trane chiller plant. Turning the chillers, pumps, valves and other devices on and off is done manually.

The plant has two 15-hp chilled water pumps. Only one of the two pumps (Pump 1) was operating during the period of measurement. The chilled water pump motors have continuously variable speed control, but the speed must be set manually – there is no automatic control.

There are two 15-hp condenser water pumps, of which one (Pump 3) ran during the monitored period. Like the chilled water pumps, the motors are equipped with manual speed control.

Chilled water pipes connect the two chiller plants, so the main plant can provide cooling to Data Center 4.1 if the data center plant goes off-line.

The data center chilled water plant has a pair of closed circuit, indirect cooling towers. Each cooling tower has two constant-speed fan motors. One motor drives two fans, and the other motor drives the remaining fan. Cooling tower 2 ran during the monitored period; cooling tower 1 did not. The condenser water is not mixed with the cooling tower water; it remains in closed pipes, while the cooling tower water wets the outside surface of the pipes. During the first stage of cooling, the fans remain off and a pump in the cooling tower sprays water over the pipes. For additional cooling both fan motors will turn on and off together as needed to meet the condenser water set point.

The use of closed-circuit cooling towers eliminates the need for the treatment chemicals normally used in condenser water. This allows the condenser water to be used as reheat water for the CRAC units (Figure 7). The reheat loop includes a reheat boiler, hot water coils in the CRAC units, and the condenser of Chiller 1. This arrangement is an energy-saving measure; it allows using waste heat from the chiller to warm the reheat water.

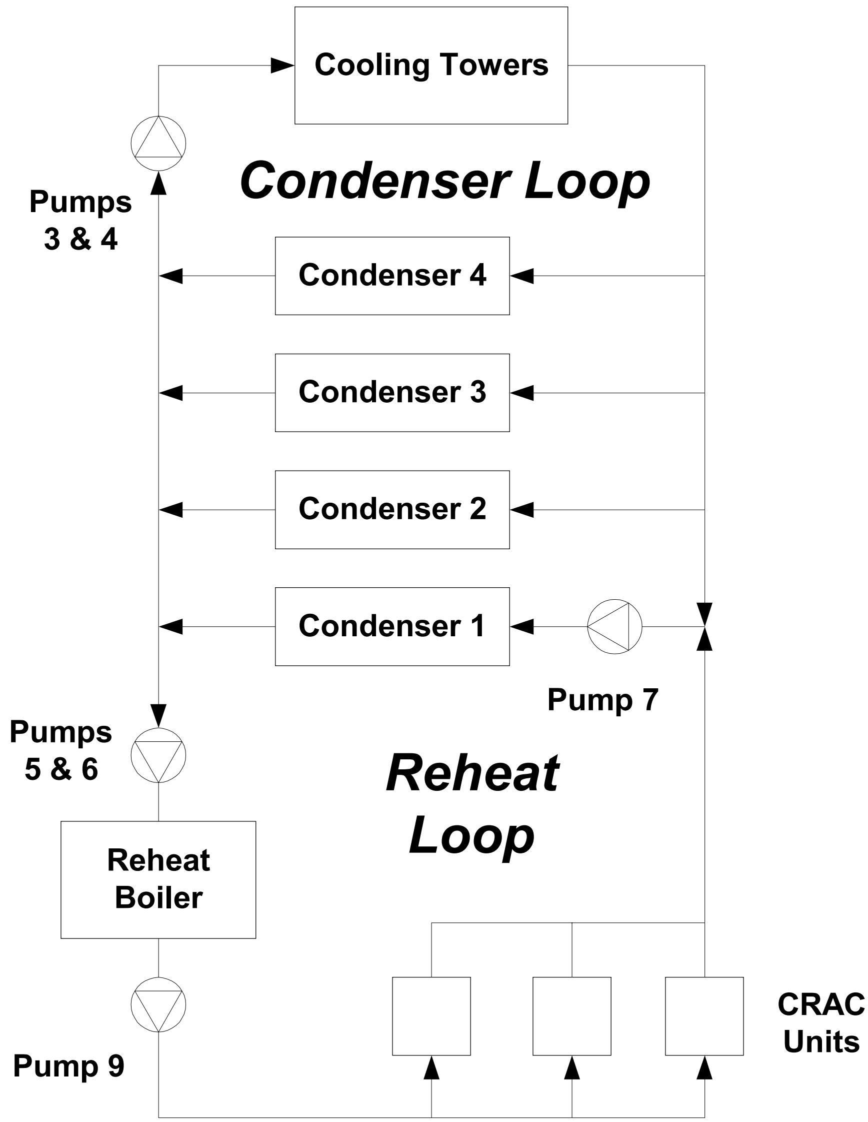
Typically the reheat boiler is not operated, though a reheat pump is normally operating.[5]

Condenser water is pumped through the condensers of all four chillers, regardless of the number of chillers operating.

The plant is plumbed to allow waterside economizing, called "Winter Cooling" in this facility. There is no heat exchanger; instead, the water in the chilled water loop is diverted directly to the cooling towers when waterside economizing is desired.[6] This plant is unusual because the same water can be used for the condenser loop, the reheat loop, and the chilled water loop.

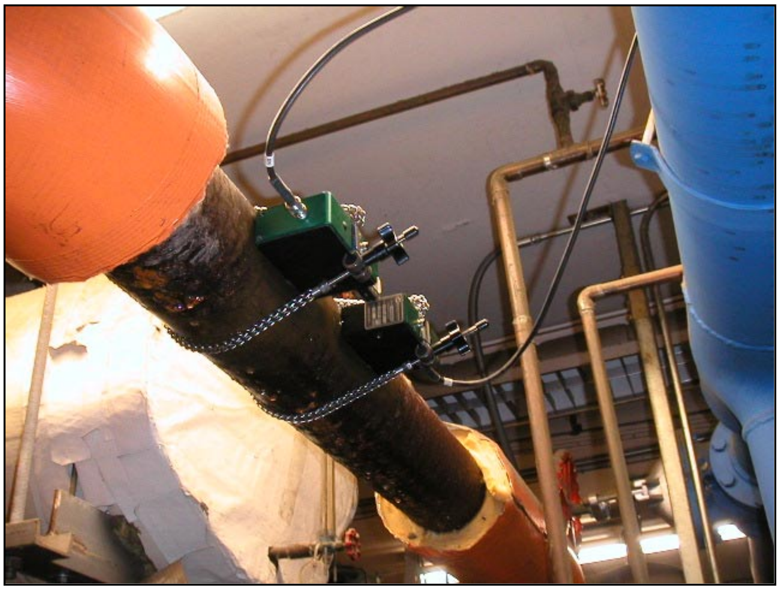
[5] The reheat boiler hasn't been on in the last 3 years, according to maintenance crew, yet a reheat pump (Pump 7) still runs continuously.
[6] According to the maintenance crew, this feature hasn't been used in recent years.

Figure 7. Simplified Schematic of Reheat and Condenser Loops in Data Center Chiller Plant



Note: This diagram shows only the condenser and reheat loops; it does not include the chilled water loop.

Figure 8. Measurement of Chilled Water Flow



Power consumption, flow, and chilled water temperatures[7] were measured in the chiller plant over two days; see Table 3. The outside air temperature, relative humidity, and chiller measurements did not vary much during the monitored period. Appendix A contains graphs of the recorded data.

CRAC UNITS

The chilled water system serves water-cooled CRAC units in the data centers.

The CRAC units in Data Center 4.1 are constant-speed air handlers, equipped with electrically powered humidifying units. The CRAC units are fed three types of water – chilled water for cooling and dehumidifying, reheat water for reheating the air after dehumidifying; and deionized water for humidification. There are a total of six identical CRAC units in this data center, but only three were operating during the period of measurement. The units are turned on and off manually by the maintenance crew. According to facility staff, only three units are needed to satisfy the room set point during most of the year.

Air enters through filters in the top of the CRAC, and exits from the bottom to the underfloor space. The CRAC unit controls are set to maintain a return air temperature of 72 °F ± 2 °F, and a relative humidity of 50% ± 2%. These are relatively narrow ranges, and are a holdover from the time the data centers used mainframe computers. The actual

[7] These were measured using a Summit Technology PowerSight PS3000 for electric loads, a Controlotron ultrasonic flow meter for chilled water flow, and a Pace Scientific Pocket Logger equipped with thermistors to measure the chilled water supply and return temperatures.

room air temperature and relative humidity were not measured directly by the investigation team. Temperature and relative humidity sensors are installed approximately in the middle of data centers (Figure 3). There is a data recorder for temperature and humidity, which was maintained by the facility engineers. The temperature and humidity remained fairly constant throughout the monitoring period. The temperature was around 72.5±0.5°F, while the relative humidity was around 49%±1%.

Figure 9. CRAC 7 in Data Center 4.1

Chilled water flow, and chilled water supply and return temperatures were measured at CRAC 7 for two days.[8] A spot measurement was made of the electrical power usage of CRAC 7. The other two CRAC units in operation (9 and 10) were assumed to have the same cooling and electrical load. This is a reasonable assumption, as the room has a large volume and is sparsely occupied. Even though the computer equipment is not distributed evenly (there are areas of the room that are used for storage) it is unlikely that there are any "hot spots". The ambient conditions for each CRAC unit are assumed to be essentially the same. The CRAC units are identical, constant-speed units, so the fan speed (and power) is assumed to be the same. The temperature and humidity set points were confirmed to be the same by examining the control panel on the front of each CRAC unit.

The spot measurements and the average of trended measurements are listed in Table 3. Refer to Appendix A for a graph of the CRAC 7 chilled water flow and temperature measurements over the entire monitoring period. The actual airflow through the CRAC unit was not measured.

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[8] Flow was measured with a Controlotron ultrasonic flow meter attached to the supply line, and temperatures were recorded with a Pocket Logger reading signals from thermistors tucked under the insulation of the chilled water supply and return lines.

Table 3. Cooling Equipment Electrical and Load Measurements

Equipment	Nominal Size	Spot / Monitored	Date(s)	Average Value
Chiller 3 Power	n/a	Monitored	11/13/02 - 11/15/02	46.6 kW
Chiller 3 Load	100 tons	Monitored	11/13/02 - 11/15/02	45.8 tons
Chilled Water Pump (Pump 1)	15 hp	Monitored	11/13/02 - 11/15/02	10.1 kW
Condenser Water Pump (Pump 3)	15 hp	Spot	11/13/02	13.2 kW
Reheat Water Pump (Pump 7)	5 hp	Estimated[9]	--	2.9 kW
Cooling Tower 2, Fan 1	15 hp	Monitored	11/13/02 - 11/15/02	0.3 kW
Cooling Tower 2, Fan 2	7.5 hp	Spot	11/15/02	0.2 kW
Cooling Tower 2 Spray Pump	5 hp	Spot	11/13/02	4.0 kW
CRAC 7 Power	n/a	Spot	11/14/02	6.1 kW
Total CRACs Power (Units 7, 9, and 10)	--	Multiply by 3	--	18.3 kW
Amount of heat being removed from Data Center 4.1 by CRAC 7	n/a	Monitored	11/13/02 - 11/15/02	7.4 tons
Amount of heat being removed from Data Center 4.1 by CRAC Units 7, 9 and 10	--	Multiply by 3	--	22.1 tons

During the monitored period Chiller 3 delivered an average of 45.8 tons of cooling, approximately one-half of its nominal 100-ton capacity. This is only one-eighth of the total Trane chiller plant capacity.

The power consumption of the chilled water pump (Pump 1) is reasonable for a 15-hp motor, assuming 90% efficiency and a load factor of 81%. [(15 hp)(0.746 kW/hp)(81%)/(90%) = 10.1 kW.] Assuming the condenser pump (Pump 3) has the same efficiency, it appears to be overloaded by about 6%, but this is not an uncommon motor service factor. [(15 hp)(0.746 kW/hp)(106%)/(90%) = 13.2 kW.]

The cooling tower fans cycled regularly during the monitored period. The fan power shown in Table 3 are average values. The total electric power consumption of the CRAC units in Data Center 4.1 is essentially the sum of the electric power draw of the fan motor

[9] Gould E-Plus 5 hp motor; assumed 75% loaded, 95% efficient.

in each unit. This fan power represents 33% of the total HVAC power consumption. This power usage can probably be reduced; strategies are described in Section V—Energy Efficiency Recommendations, below.

DATA CENTER 4.1: LIGHTING

Lighting in Data Center 4.1 consists of T-8 fluorescent lamps with electronic ballasts. There are two lamps and one ballast per fixture. The room is equipped with occupancy sensors, though the facility operates 24 hours a day, 7 days a week. Foot traffic is frequent enough, and sensor delay long enough, that the lights rarely turn off, according to facility staff. The measurement team on this study supports this observation. All the lights were on during the monitored period. Counting the number of fixtures and multiplying by per-fixture wattage estimated the total lighting power:

(127 two-lamp fixtures) x (71 Watts/fixture) = 9.0 kW

The lighting power density is 1.0 Watts per square foot of gross floor area.

DATA CENTER 4.1: SUMMARY MEASUREMENTS AND METRICS

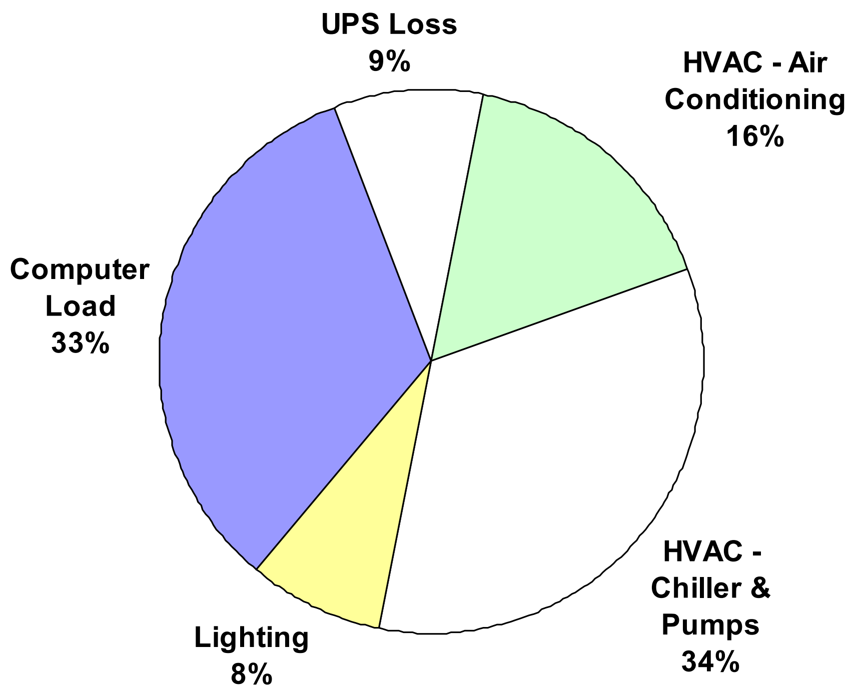
SUMMARY MEASUREMENTS

Table 4 brings together all the electrical measurements for the data center. The total UPS loss is split proportionally between the data centers, according to the critical load in each. Likewise, Data Center 4.1's share of the total electric power consumption of the dedicated chilled water plant is determined by the ratio of the measured cooling tons of the Data Center 4.1 CRAC units to the measured tonnage of the chiller plant.

Table 4. Summary of Electrical Measurements

Item	Remarks	Value	Percent
Computer Loads	Critical and non-critical	36.7 kW	33%
UPS Loss	Data Center 4.1 share of total UPS loss	10.0 kW	9%
HVAC – Air Movement	Fan power for CRAC Units 7, 9, 10	18.3 kW	16%
HVAC – Chilled Water Plant	Data Center 4.1 share of total chilled water plant power consumption	37.3 kW	34%
Lighting	--	9.0 kW	8%
Total Power Use	--	111.3 kW	100%

Figure 10. Energy Balance, Data Center 4.1



The total computer load is 33% of the data center electric power usage. The electricity used to cool the data center significantly outweighs this; pumping and cooling power accounts for 34% of the total, and air conditioning amounts to 16% of the data center electric power usage. UPS losses account for 9% of the data center electric power usage, and the lights account for the remaining 8%.

ELECTRICAL CONSUMPTION METRICS

Table 5 addresses the issue of data center load density. The most commonly used metric among mission critical facilities is the computer load density in Watts consumed per square foot (W/sf). However, even in a prototypical data center filled entirely with closely spaced racks of similar equipment, the choice of what to use as square footage is not always consistent between analysts, and can be a source of confusion.[10] In the case of Data Center 4.1, there is wide variety of operating equipment in the room, for instances, servers in racks, stand-alone servers, stand-alone PCs, tape drives, printers.

[10] See "Data Center Power Requirements: Measurements from Silicon Valley", by Mitchell-Jackson, Koomey, Nordman, & Blazek, December 2001. It is available on the web at http://enduse.lbl.gov/Info/Data_Center_Journal_Articl2.pdf.)

Less than 10% of gross floor areas are occupied by the equipment, which includes all types of computer equipment.

Table 5. Electrical Consumption Metrics

Metric	Value	Units
Data Center Gross Area	8,900	sf
Computer Equipment Area	800	sf
Computer Load Density based on Gross Area	4.1	W/sf
Current Computer/Equipment Occupancy	9	%

"Data Center Gross Area" is the entire floor area of the room, including storage areas and the main aisles. Per the Uptime Institute Definitions, this gross floor space is what facility engineers typically use when calculating a computer load density (W/sf).[11] "Computer Equipment Area" is the portion of the room occupied by all computer equipment, not including the narrow aisle space immediately around the equipment.

The total computer equipment load is 36.7 kW. The computer load density based on the gross area is 4.1 W/sf. Compared to typical 30 to 50 W/sf as seen in other facilities with relatively tight packing, this computer load density is rather low largely because of its sparse distribution. Typical data centers contain tall racks set close together in rows, with a narrow aisle between each row. Each slot in a rack can contain a board with one or more processors on it. For the purpose of estimating the maximum potential build-out of the data center, it is assumed that more of the same general type of equipment will be added to the footprints of data center floor space. This would theoretically result in the computer load density of no more than 45 W/sf, while the total computer load at 100% occupancy would increase up to 400 kW.

HVAC Efficiency Metrics

Since the packing of data centers and computer types are site specific, a more useful metric for evaluating how efficiently the data center is cooled can be represented as a ratio of cooling power to computer power. Another metric is the "theoretical cooling load". It is the sum of the computer, lighting, and CRAC fan motor loads. All of these loads equate to heat that must be removed from the room. Though there is a small amount of human activity, this is insignificant compared to the other loads.

[11] Users look at watts per square foot in a different way. With an entire room full of communication and computer equipment, they are not so much concerned with the power density associated with a specific footprint or floor tile, but with larger areas and perhaps even the entire room. Facilities engineers typically take the actual UPS power output consumed by computer hardware and communication equipment in the room being studied (but not including air handlers, lights, etc.) and divide it by the gross floor space in the room. The gross space of a room will typically include a lot of areas not consuming UPS power such as access aisles, white areas where no computer equipment is installed yet, and space for site infrastructure equipment like Power Distribution Units (PDU) and air handlers. The resulting gross watts per square foot (watt/ft2-gross) or gross watts per square meter (watt/m2-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting.

Chiller efficiency is usually presented as the ratio of chiller power at full load to the tons of cooling provided at full load, in units of kW/ton. HVAC system efficiency is similar, but it takes in to account the power consumption of all the HVAC system components – chiller, cooling tower, pumps, and air handlers.

Table 6. HVAC Efficiency Metrics

Metric	Average Value	Units
Cooling kW / Computer Load kW	1.5	--
Theoretical Cooling Load	18.2	tons
Cooling Provided by HVAC System	22.1	tons
Chiller Efficiency	1.0	kW/ton
HVAC System Efficiency	2.5	kW/ton

The "Cooling Effectiveness Index " is 1.5 kW/kW (a lower number corresponds to more effective cooling). This indicates that in Data Center 4.1, for every unit of electric power used by computer equipment, 1.5 units of electric power is being used by cooling to maintain the conditions of the data center. This figure does not include the efficiency loss in the UPS, or the power required to keep the UPS cool.

In the case of Data Center 4.1 the theoretical load is 20% less than the measured cooling delivered by the HVAC system. There are several possible explanations for this. The non-critical load may be underestimated. Some heat may be entering the data center from adjoining rooms. Or, CRAC units 8 and 9 may be providing a little less cooling than CRAC unit 7. The chiller efficiency is 1.0 kW/ton. Though this is typical for an older reciprocating unit, newer water-cooled chillers are much more efficient. For the portion of the chilled water system that serves Data Center 4.1, plus the CRAC units in that room, the overall HVAC system efficiency is 2.5 kW/ton. An unusually large portion of the HVAC power consumption is due to the CRAC units, even though these units consist mainly of a fan and cooling coil, and do not perform a refrigeration process.

Strategies for improving efficiency are addressed later in this report.

DATA CENTER 4.5: DATA EQUIPMENT

As in Data Center 4.1, there are critical and non-critical computer loads. The critical load was measured directly, and the non-critical load was estimated. For details of the estimation, see Appendix B. As in Data Center 4.1, the non-critical load is relatively small. The total estimated load – 41.4 kW – is used in summary calculations and the distinction between critical and non-critical is no longer made.

Table 7. Data Equipment Loads

	Electrical Use	Units
Critical	40.6	kW
Non-Critical	0.8	kW

Figure 11. Servers in Data Center 4.5

DATA CENTER 4.5: COOLING SYSTEM

Data Center 4.5 contains ten identical split-system, air-cooled CRAC units. They are Data-Aire units, model DAAD-2034. See Appendix C for specifications. The compressor, evaporator, air delivery fan, and humidifier for each system are in a single housing (the "evaporator unit") that stands inside Data Center 4.5. The units have two stages of cooling. They are capable of dehumidification; reheat is provided by waste heat from the compressor. The warm refrigerant is piped to the rooftop condenser units where it passes through a refrigerant-to-air heat exchanger, before returning to the evaporator unit. Four multi-speed fans in the condenser unit stage on as needed, to cool the refrigerant to the desired temperature.

Figure 12. Air-Cooled Condensers on Roof

During the period of measurement, only four of the ten evaporator units were running – CRAC units 23, 24, 25 and 28. The outside dry bulb air temperature varied between 50 °F and 60 °F during this time, and the outside air relative humidity varied between 80% and 100%. A chart of outside air conditions is included in Appendix A. The remaining evaporator units were shut off. Facility staff reports they are not needed to keep the room at the desired temperature. The CRAC units control to the same narrow standard as in Data Center 4.1: a return air temperature of 72 °F ± 2 °F, and a relative humidity of 50% ± 2%. The actual room air temperature and relative humidity were not measured directly by the investigation team. There is a data recorder for temperature and humidity within the data center space, which was maintained by the facility engineers. The temperature and humidity remained fairly constant throughout the monitoring period. The temperature was around 70±1°F, while the relative humidity was around 52%±1%.

The display panel on CRAC 23 indicated it was in dehumidifying mode, unlike the other three operating CRAC units. The power consumption of the evaporator and condenser units of CRAC 23 was monitored for about 18 hours. A spot measurement was taken of the evaporator power for CRAC 24. The spot measurements and average of trended measurements are listed in Table 8. Refer to Appendix A for graphs of the measurements over the entire monitored period. The actual airflow through the CRAC units was not measured.

Table 8. Cooling Equipment Electrical Measurements

Equipment	Spot / Monitored	Date(s)	Average Value
CRAC 23, Evaporator Unit	Monitored	11/14/02 – 11/15/02	12.2 kW
CRAC 23, Condenser Unit	Monitored	11/14/02 – 11/15/02	0.7 kW
CRAC 24, Evaporator Unit	Spot	11/13/02	4.3 kW
Total Evaporator Unit Power, CRAC Units 23, 24, 25, 28	Sum	--	33.0 kW
Total CRAC Unit Power, Units 23, 24, 25, 28	Sum	--	34.4 kW

CRAC 23 consumed almost 3 times as much power as CRAC 24, and the consumption was steady during the monitored period. Based on the power consumption measurements, it appears that only the fan in CRAC 24 was operating, and the unit was not doing any active cooling. This assertion is supported by the analysis in Appendix C. If true, then the CRAC 23 compressor power is assumed to be 12.2 kW – 4.3 kW = 7.9 kW. (Evaporator Unit Power minus Fan Power equals Compressor Power.) Based on the analysis, it is assumed that two of the four CRAC units were operating like CRAC 23 (compressor operating), and the remaining two were operating like CRAC 24 (compressor not operating).

DATA CENTER 4.5: LIGHTING

The type of light fixtures and the number of operating hours in Data Center 4.5 are identical to Data Center 4.1, with a different number of fixtures. All the lights were on during the monitored period. The total lighting power is calculated by multiplying the number of fixtures by 71 Watts/fixture.

(120 two-lamp fixtures) x (71 Watts/fixture) = 8.5 kW

The lighting density is 0.99 Watts per square foot of gross floor area, very similar to the 1.02 W/sf value for Data Center 4.1.

DATA CENTER 4.5: SUMMARY MEASUREMENTS AND METRICS

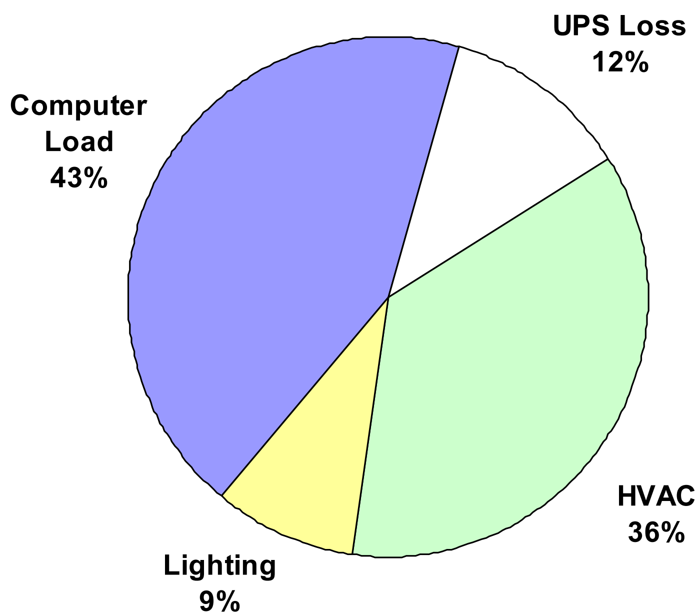
SUMMARY MEASUREMENTS

Table 9 brings together all the electrical measurements for the data center. The total UPS loss is split proportionally between the data centers, according to the critical load in each.

Table 9. Summary of Electrical Measurements

Item	Remarks	Average Value	Percent
Computer Load	Critical and non-critical	42.6 kW	43%
UPS Loss	Data Center 4.5 share of total UPS	11.1 kW	12%
HVAC	Total power consumption of four CRAC units: 23, 24, 25, 28	34.4 kW	36%
Lighting	--	8.5 kW	9%
Total Power Use	--	96.7 kW	100%

Figure 13. Energy Balance, Data Center 4.5



The critical computer load served by the UPS, plus the non-critical computer load, amounts to 43% of the data center electric power usage. Cooling Power, including air movement, is the second largest consumer at 36% of the data center electric power usage. UPS loss accounts for 12% of the data center electric power usage, and the lights account for the remaining 9%.

ELECTRICAL CONSUMPTION METRICS

Unlike Data Center 4.1, computer equipment is spread uniformly over the entire floor area of Data Center 4.5. However, the equipment floor density is also very low – they occupy 600 ft^2 out of the total data center floor area of 8,560 ft^2. The aisles between equipment are wide, and the four work cubicles that have been set up do not interrupt the uniformity of computer placement. The cubicles were staffed continuously during the period of measurement, but the heat load represented by the occupants is negligible in comparison to the equipment. Given this arrangement, only the computer load density based on gross data center area is shown in Table 10.

Table 10. Electrical Consumption Metrics

Metric	Value	Units
Data Center Gross Area	8,560	sf
Computer Equipment Area	600	sf
Computer Load Density based on Gross Area	4.8	W/sf
Current Computer/Equipment Occupancy	7	%

The total computer load is 41.4 kW. The actual computer load density based on the gross area is 4.8 W/sf, which is well below current typical load densities largely due to rather sparse computer equipment occupancy. Based on information provided by the facility engineers , it is estimated that Data Center 4.5 is about 7% occupied. Assuming that more computer equipment of the same type would be added, and that the room would be built out to 100% occupancy in terms of footprints, the computer load density would theoretically be no more than 68 W/sf, while the total computer load would theoretically increase up to 590 kW.

HVAC EFFICIENCY METRICS

The theoretical cooling load is calculated in the same manner as for Data Center 4.1. Time constraints did not allow direct measurement of the cooling provided by the CRAC units. The total cooling provided was estimated after analyzing the specifications for the CRAC unit. See Appendix C for details.

Table 11. HVAC Efficiency Metrics

Metric	Average Value	Units
Cooling kW / Computer Load kW	0.8	--
Theoretical Cooling Load	19.1	tons
Estimated Cooling Provided by CRAC Units	16.8	tons
Estimated CRAC Unit Efficiency	1.4	kW/ton

The “Cooling Effectiveness Index ” is 0.8 kW/kW (a lower number corresponds to more effective cooling) in Data Center 4.5. This indicates that the cooling in this data center is almost twice as effective as the cooling in Data Center 4.1 with the "Cooling Effectiveness Index " of 1.5 kW/kW. Although water-cooled chiller systems are typically more efficient than air-cooled, the discrepancy in this case is due to a combination of the following likely reasons: 1) that the chilled water plant serving Data Center 4.1 is very much under loaded, resulting in inefficient operation; 2) that Data Center 4.1's chilled water plant has old reciprocating chillers, which are less efficient than centrifugal, screw, or scroll chillers; 3) that computer equipment are much more evenly spread out in Data Center 4.5, which likely mitigates the cooling demand across the whole data center; and 4) that CRACs in Data Center 4.1 might have been overly used.

The theoretical cooling load in Data Center 4.5 is 19.1 tons, similar to Data Center 4.1's theoretical cooling load of 18.2 tons. This is expected, given that the two data centers have an essentially similar scale of floor area, and contain similar types and quantities of computer equipment, lights, and CRAC unit fan motors. The estimated cooling provided by the CRAC units in Data Center 4.5 is 12% lower than the theoretical load the CRAC units are serving. As both numbers are estimates, this is reasonable agreement. The amount of cooling provided by the CRAC units, and their efficiency, were estimated by the method described in Appendix C.

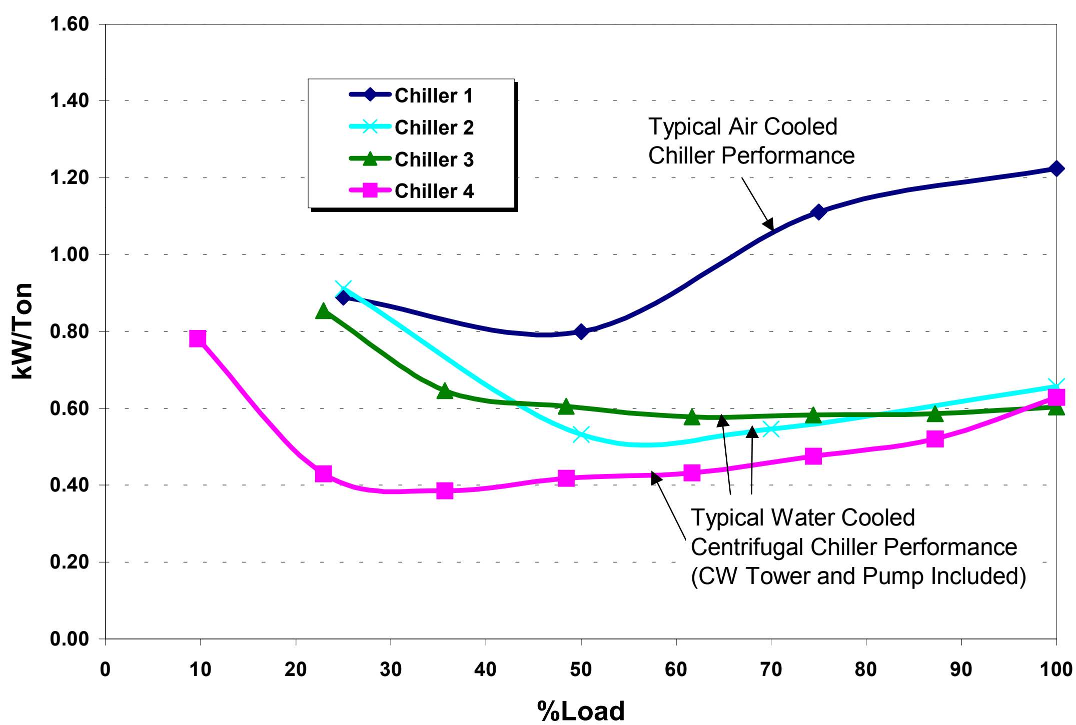
V. Energy Efficiency Recommendations

General Guidelines for Future Construction

Efficient Chilled Water System

Water-cooled chillers offer enormous energy savings over air-cooled chillers, particularly in dry climates, because they take advantage of evaporative cooling. Since the chiller is being cooled by lower temperature media, it can reject heat more easily, and does not have to work as hard. Though the addition of a cooling tower adds maintenance costs associated with the water treatment, we have found that the energy savings outweigh the maintenance costs. Within the options of water cooled chillers, variable speed centrifugal are the most energy efficient, because they can operate very efficiently at low loads. The graph below compares the energy performance of various chiller types.

Comparison of Typical Chiller Efficiencies over Load Range

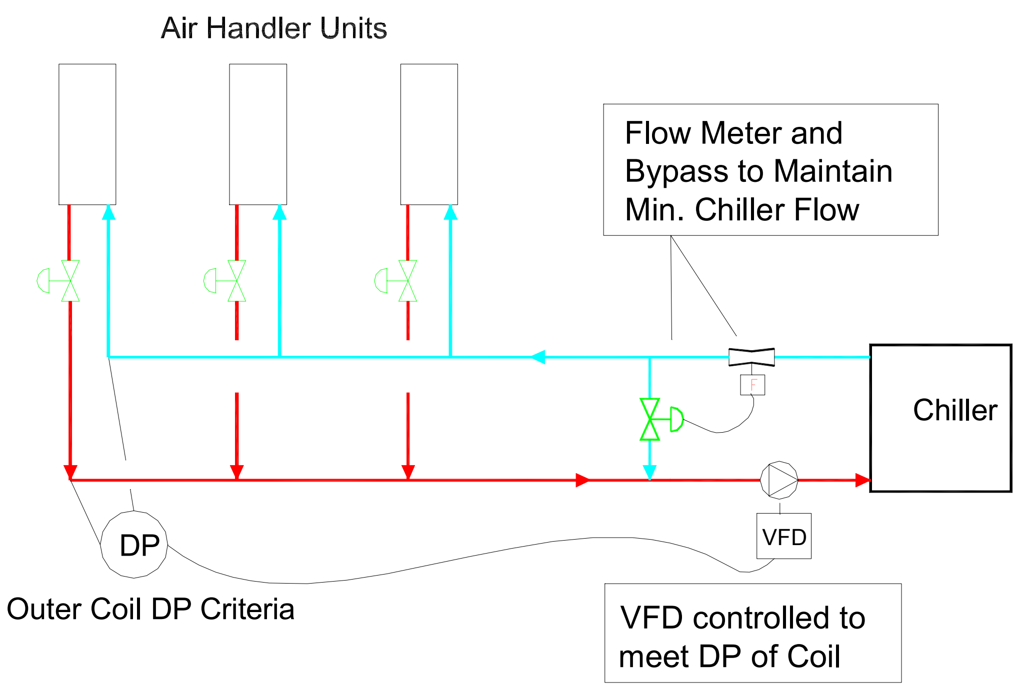


Chiller 1	250-Ton, Screw, Standard Efficiency, Air Cooled
Chiller 2	216 Ton, Screw, Water Cooled
Chiller 3	227-Ton, Centrifugal, Constant Speed, Water Cooled
Chiller 4	227-Ton, Centrifugal, Variable Speed, Water Cooled

Though there are efficient air cooled chillers, the larger size of water cooled chillers has resulted in more care given to efficiency and life cycle costs compared to air cooled chillers.

The selection of the auxiliary equipment, including the cooling tower, pumps, and pumping strategy should also be considered carefully. For example, variable speed fans on cooling towers allow for optimized cooling tower control. Premium efficiency motors and high efficiency pumps are recommended, and variable speed pumping is a ripe opportunity for pump savings. Variable pumping strategies can be achieved in a primary/secondary scheme, where the primary pumps operate at constant speed and directly feed water to the chiller, and the secondary pumps are variable speed and serve the air-handling units. A more energy efficient scheme is primary-only variable speed pumping strategy. Pumping savings are based on the cube law: pump power is reduced by the cube of the reduction in pump speed, which is directly proportional to the amount of fluid pumped.

A primary only variable pumping strategy must include a bypass valve that ensures minimum flow to the chiller, and the use of two-way valves at the air-handling units in order to achieve lower pumping speeds. The control speed of the bypass valve should also meet the chiller manufacturers recommendations of allowable turndown, such that optimum chiller efficiency is achieved.[12] The diagram below describes the primary-only variable speed pumping strategy.



[12] This basically means that the flow through the chiller should be varied slow enough such that the chiller is able to reach a quasi-steady state condition and able to perform to its maximum efficiency.

Air Management – HVAC Design

The standard practice of cooling data centers employs an underfloor system fed by CRAC units. There are a number of potential problems with such systems: an underfloor system works on the basis of thermal stratification. This means that as the cool air is fed from the underfloor, it absorbs energy from the space, warming up as a result, and rises. In order to take advantage of thermal stratification, the return air must be collected at the ceiling level. CRAC units often have low return air grills, and are therefore, simply recirculating cool or moderately warmed air. Furthermore, they are often located along the perimeter of the building, and not dispersed throughout the floor area, where they can more effectively treat warm air. One alternative is to install transfer grills from the ceiling to the return grill. Another common problem with underfloor supply is that the underfloor becomes congested with cabling, increasing the resistance to air flow. This results in an increase in fan power use. A generous underfloor depth is essential for effective air distribution (we have seen 3 feet in one facility).

An alternative to underfloor air distribution is high velocity overhead supply, combined with ceiling height return. A central air handling system can be a very efficient air distribution unit. Design considerations include using VFDs on the fans, low-pressure drop filters, and coils. An additional advantage of a central air handling system is that it can be specified with an economizer function. With the favorable climate in the Bay Area, economizing can reduce the cooling load for a majority of the hours of the year.

Another common problem identified with CRAC units is that they are often fighting each other in order to maintain a constant humidity set point. Not only is a constant humidity set point unnecessary for preventing static electricity (the lower limit is more important), but also it uses extra power. A central air-handling unit has a better ability to control overall humidity than distributed CRAC units.

Air Management – Rack Configuration

Another factor that influences cooling in data centers is the server rack configuration. It is more logical for the aisles to be arranged such that servers' backs are facing each other, and servers' fronts are facing each other. This way, cool air is draw in through the front, and hot air blown out the back. The Uptime Institute has published documents describing this method for air management.[13] Our observations of both data centers showed an inconsistent rack configuration.

Commissioning of New Systems and Optimized Control Strategies

Many times the predicted energy savings of new and retrofit projects are not fully realized. Often, this is due to poor and/or incomplete implementation of the energy efficiency recommendations. Commissioning is the process of ensuring that the building systems perform as they were intended to by the design. Effective commissioning

[13] http://www.upsite.com/TUIpages/whitepapers/tuiaisles.html

actually begins at the design stage, such that the design strategy is critically reviewed. Either the design engineer can serve as the commissioning agent, or a third party commissioning agent can be hired. Commissioning differentiates from standard start-up testing in that it ensures systems function well relative to each other. In other words, it employs a systems approach.

Many of the problems identified in building systems are often associated with controls. A good controls scheme begins at the design well. In our experience, an effective controls design includes 1) a detailed points list, with accuracy levels, and sensor types, and 2) a detailed sequence of operations. Both of these components are essential for successfully implementing the recommended high efficiency chilled water system described above. Though commissioning is relatively new to the industry, various organizations have developed standards and guidelines. Such guidelines are available through organizations like the Portland Energy Conservation Inc., at www.peci.org, or ASHRAE, Guideline 1-1996.

Lighting Controls

Lighting controls such as occupancy sensors may be appropriate for areas that are infrequently or irregularly occupied. If 24-hour lighting is desired for security reasons, scarce lighting can be provided at all hours, with additional lighting for occupied periods.

SPECIFIC RECOMMENDATIONS

Uninterruptible Power Supply

UPS.1. Consider Replacing the UPS

The UPS nameplate indicates an efficiency of 92%; the actual efficiency was measured at 78.5%. This is likely a result of unloading the unit to the point where is operating at only 28% of its nominal capacity of 450 kW. As a result, 27.3 kW of electricity is continuously converted into waste heat. In addition, this heat has to be removed from the UPS room by a dedicated package-cooling unit. If we assume the efficiency of this cooling unit is constant at 1.0 kW/ton (a reasonable number for an efficient package unit), and electricity cost is $0.10/kWh, then the annual cost of this UPS inefficiency is about $30,000. A new, appropriately sized UPS can run at 93% efficiency. Given the same preceding assumptions, such a new unit would reduce the annual inefficiency cost by two-thirds.

UPS.2. Consider Placing More Load on the UPS

Another approach is to place more of the facility's computer equipment on the UPS, to bring its load closer to its nominal 450 kW. Assuming the UPS is still capable of operating at or near its nameplate efficiency of 92%, this strategy would confer the advantages described in measure UPS.1, as well as protecting more equipment in the event of a power outage.

Both Data Centers

These recommendations apply to both data centers. Recommendations specific to each data center follow.

DC 4.0 - 1. Run Fewer CRAC Units

The three operating CRAC units in Data Center 4.1 are lightly loaded. The cooling delivered by CRAC 7 was measured at 7.4 tons, and CRAC units 9 and 10 are assumed to be similarly loaded. The fans in each of these units run at constant speed and use a total of 18.3 kW, which is a relatively high 33% of total HVAC power consumption. If Data Center 4.1 can maintain temperature uniformity by running only two CRAC units, each at 11 tons, then the cost of running the third fan can be saved. If electricity costs $0.10 per kWh, then this will avoid about $5,350 a year in fan power.

Data Center 4.5 is operating four CRAC units. It appears that two of them are lightly loaded (8.4 tons), and that two of them are running their fans only; i.e., the compressors do not appear to be on). The fans are constant speed and draw a continuous 4.3 kW. If electricity costs $0.10 per kWh, then each fan costs about $3,750 per year to operate. If the temperature set point can be maintained with fewer operating CRAC units, each working proportionally harder to provide the same overall amount of cooling, then this fan power can be saved.

Important Note: Care should be taken to account for the fire blocking underneath the floor. The raised floor areas are physically divided in to zones, which limits the options when turning CRAC units off. Each zone that contains computer equipment will likely need at least one operating CRAC unit.

DC 4.0 – 2. Revisit Temperature and Relative Humidity Setpoints

The temperature and relative humidity standards in the data centers – 72 °F ± 2 °F, and 50% ± 2% – are relatively narrow, and are a holdover from the time the data centers used mainframe computers. Maintaining these standards requires greater energy use. The equipment currently in the data centers can likely operate without any problems with more relaxed temperature and humidity standards.

DC 4.0 – 3. Rearrange Floor Tiles for More Effective Cooling

Some of the tiles in the data centers are perforated, to allow the cooling air to rise from the space under the floor. The investigation team noticed that many of the perforated tiles could be rearranged to more efficiently cool the computer equipment. In particular, perforated tiles should be placed in front of server racks, not behind. The cooling fans inside the servers typically draw air from the front of the rack and eject it out the back.

Directing the cooling air that is coming from the floor to rise in front of the rack will provide the optimum cooling effect.

DC 4.0 - 4. Reduce Lighting

Data Center 4.1 is large and has only intermittent visitors, yet it uses some 9 kW of lighting energy almost constantly. Consider any of the following measures:

a) Reduce the lights-on interval of the existing occupancy sensors.
b) Add more, narrow-view occupancy sensors, and wire them to specific lighting zones, so that only needed lights come on as people move through the room.
c) Add task lighting in appropriate areas, and disable a portion of the overhead lights.

The same strategy for reducing lighting energy applies to Data Center 4.5. In addition, accommodation for the regular occupants is needed. Therefore, consider introducing task-specific, efficient lighting, such as electronic-ballast compact fluorescent desk lamps. Newer models have very high quality, flicker free light, and draw as little as 18 Watts.

Data Center 4.1

DC 4.1 - 1. Turn Off the Reheat Pump (Pump 7)

The CRAC units in Data Center 4.1 are able to dehumidify the air in the room by overcooling it. To bring the air temperature back to the desired level, reheat water is required. During the two days of measurement the outside air relative humidity was continuously over 80%, and at times reached 100%, yet the reheat system did not turn on. According to maintenance staff, the reheat boiler hasn't run in the last 3 years. These observations indicate that excess humidity is not a problem in the data center.

The 5-horsepower reheat pump (Pump 7) runs continuously, and needlessly. If we assume the motor is 75% loaded, and 95% efficient, then it draws a constant 2.9 kW. If electricity costs $0.10 per kWh, this pump costs about $2,500 a year to run. It should be turned off.

DC 4.1 - 2. Use Chilled Water From the Main Plant

The four 100-ton reciprocating Trane chillers are older and almost certainly less efficient than the large centrifugal chillers in the main plant. Chilled water pipes already run from the main plant to the smaller plant, and the CRAC units can be run directly with chilled water from the main plant. We recommend that this strategy be used whenever the main plant is running. The small Trane chiller plant should be shut off during these periods. We did not measure the efficiency and operating conditions of the main plant so we are unable to calculate cost savings, but they should be significant. For the periods where the small Trane plant must be run, consider the following measures:

DC 4.1 - 3. Use Free ("Winter") Cooling

The small Trane chiller plant is designed to allow waterside economizing, also known as "free cooling". Signs in the chiller room indicate that the term "winter cooling" is also used. This strategy uses the cooling towers to produce chilled water directly when the outside air conditions are favorable; i.e., low humidity. The chillers are shut off during these periods. If normally only one chiller operates, and the chiller normally draws 50 kW, and the cost of electricity is $0.10 per kWh, then this strategy saves $5/hour of chiller energy.

The cooling towers in this plant (as well as all the other components) are sized for a much larger load than currently exists in the data centers served by the plant. The cooling towers can likely make sufficient chilled water for the data centers for a large part of the year, given Fresno's dry climate. The maintenance crew indicated that free cooling hasn't been used in a long time. Consider re-implementing this scheme. See Appendix D for a technical paper that describes the strategy in detail.

DC 4.1 - 4. Add a Variable Speed Drive to the Cooling Tower Fans

As shown by the chart in Appendix A, Fan 1 in Cooling Tower 2 is cycling on and off frequently (approximately once per hour). The fan motor uses 2 kW when it is on, but the average consumption over the monitored period was only 0.3 kW. In other words, the motor has a duty cycle of about 15%. A variable speed drive will allow the fan to run continuously and more slowly, extending the life of the equipment. If the cooling towers are called upon to handle a larger load in the future, the variable speed drive will offer significant power savings as well.

DC 4.1 - 5. Feed Condenser Water Only Through Running Chiller

The piping and valve arrangement in the small Trane chiller plant allows the condenser water to be sent selectively through only the chiller that is operating. The condenser water was observed to be flowing through all four chillers simultaneously. Shutting the valves to the 3 non-running chillers will provide several benefits:

a) The condenser pump is constant speed. Confining the condenser water flow to one condenser instead of four will increase the resistance to flow. The pump will "ride its curve", and deliver less flow at a higher pressure. Counter-intuitively, this will actually reduce its power consumption.

b) Even though the total gallons per minute (gpm) will be lower, the gpm through the single operating chiller will be higher than it was before, because the entire flow is going through a single condenser instead of four. The temperature of the condenser water leaving the chiller will be lower than it was before, which will help the chiller operate more efficiently.

c) If the chiller is rejecting the same amount of heat as before, but the total condenser water flow has been reduced, then the temperature of the condenser water going to the cooling tower will be higher than before. This will allow the cooling tower to more easily reject heat to the outdoors, which in turn allows the cooling tower fans to run less often, saving energy.

DC 4.1 - 6. Feed Chilled Water Only Through Running Chiller

The four Trane chillers are connected in series-parallel. The evaporators for Chiller 1 and 2 are piped in series, as are the evaporators for Chillers 3 and 4. Each of these pairs is then piped in parallel. As in the case of the condenser water, the piping and valve arrangement allows the chilled water to be sent only through the chiller that is running. We observed that the chilled water is flowing through both Chiller 3 and 4.

Adjusting the valves to route the chilled water only through the running chiller will reduce the resistance to flow, lowering the load on the chilled water pump. Since the chilled water pump has a variable speed control, the pump speed can be reduced accordingly, saving energy.

Data Center 4.5

DC 4.5 - 1. Investigate Dehumidifying Mode of CRAC 23

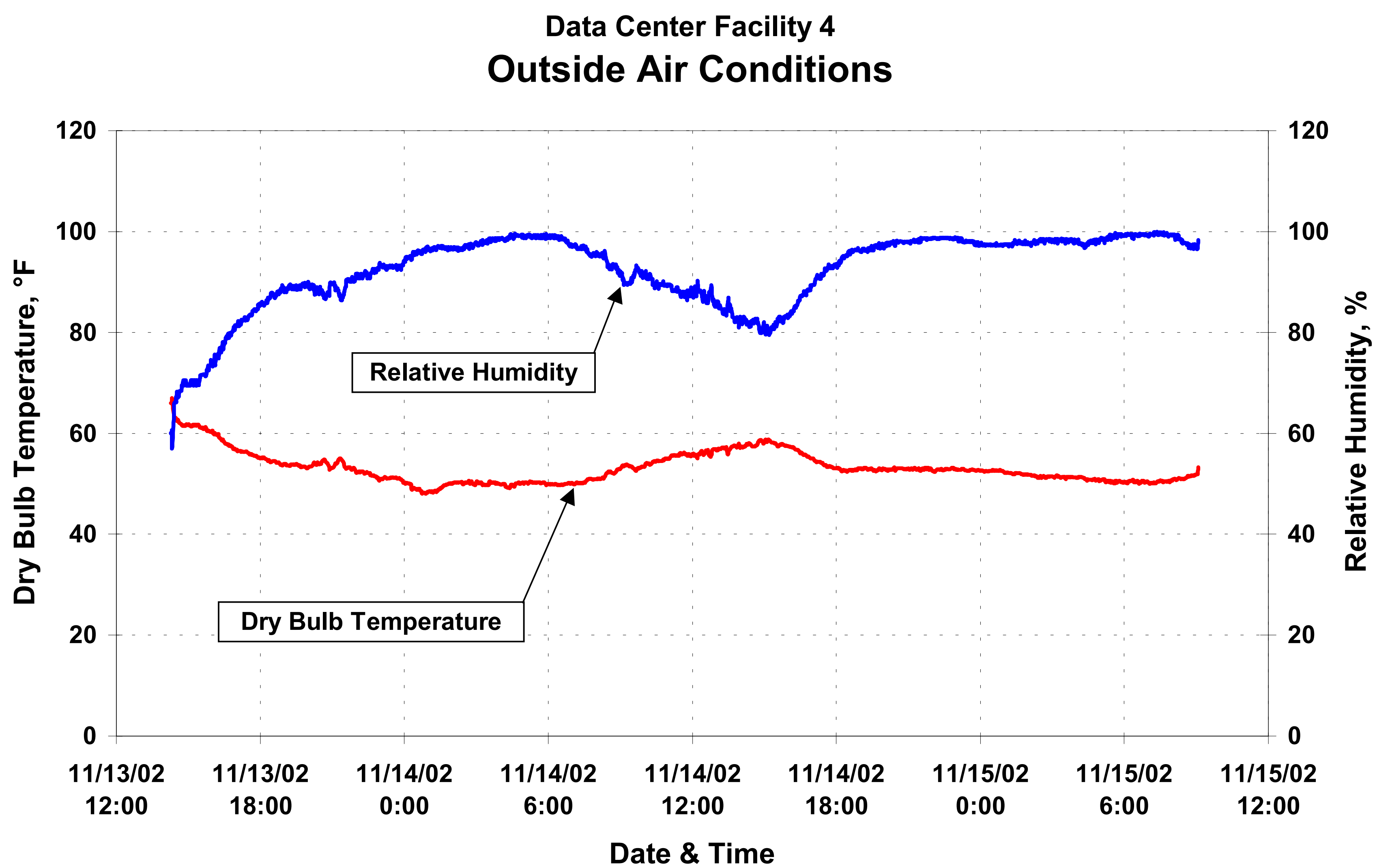
Observations in Data Center 4.1 indicate that excess humidity is not an issue in either of the data centers, yet CRAC 23 in Data Center 4.5 displayed "dehumidifying" on its front panel. It is not uncommon for CRAC unit controls to fail in dehumidifying mode. This causes unnecessary and intensive power use, and can go undetected for a long time. Measurements of CRAC 23 power did not reveal excessive usage; however, this status message bears investigation.

Several of the above recommendations – DC 4.0-4 (reduce lighting), DC 4.1-1 (turn off reheat pump), and DC 4.1.2 (use chilled water from main plant) – agree with those made in a May 2001 report presented to this facility through a Federal Energy Management Program (FEMP) study.[14]

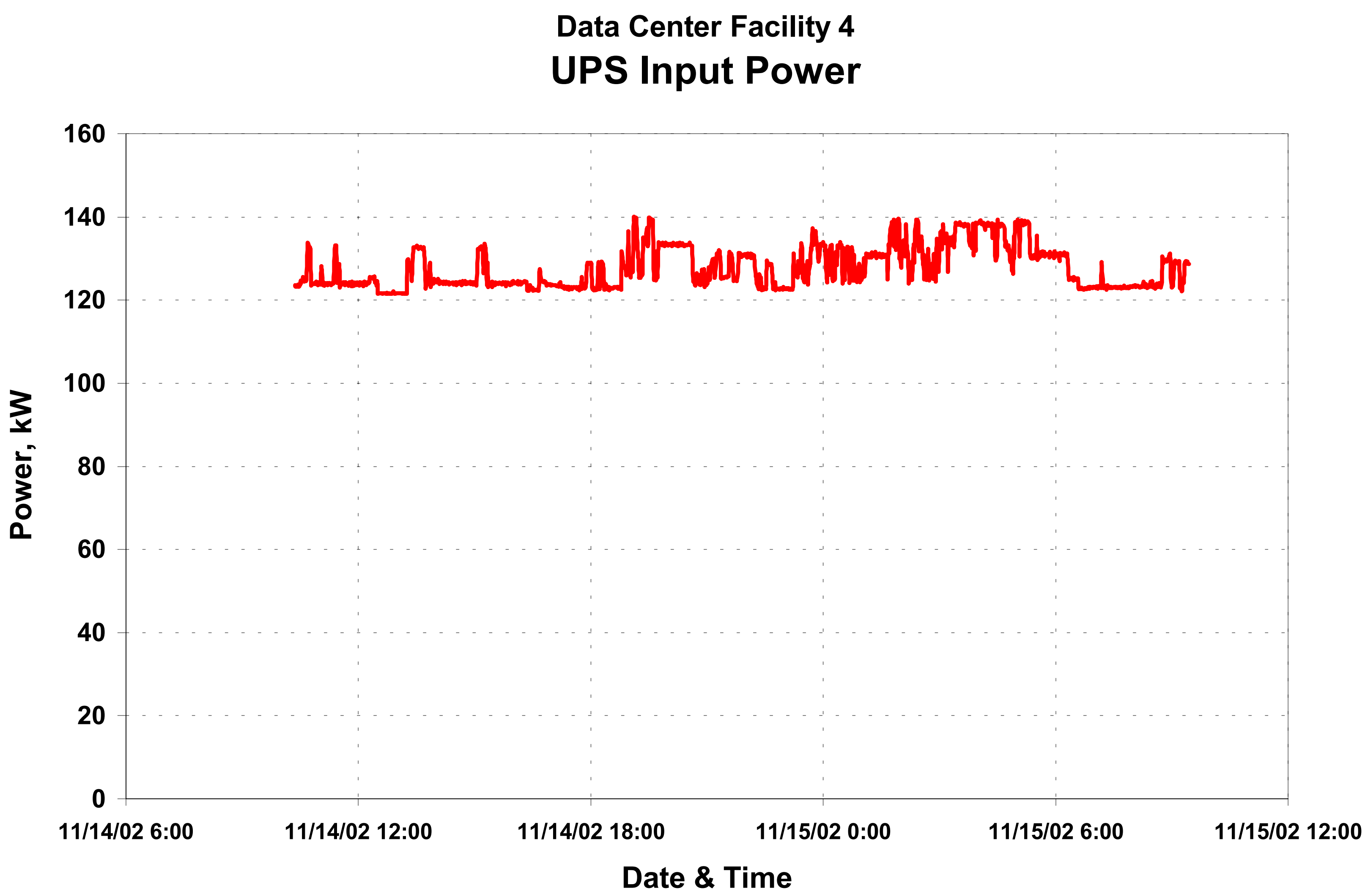
[14] "Assessment of Load and Energy Reduction Techniques (ALERT), Final Report" by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Federal Energy Management Program. Date of site visit, May 22-23, 2001.

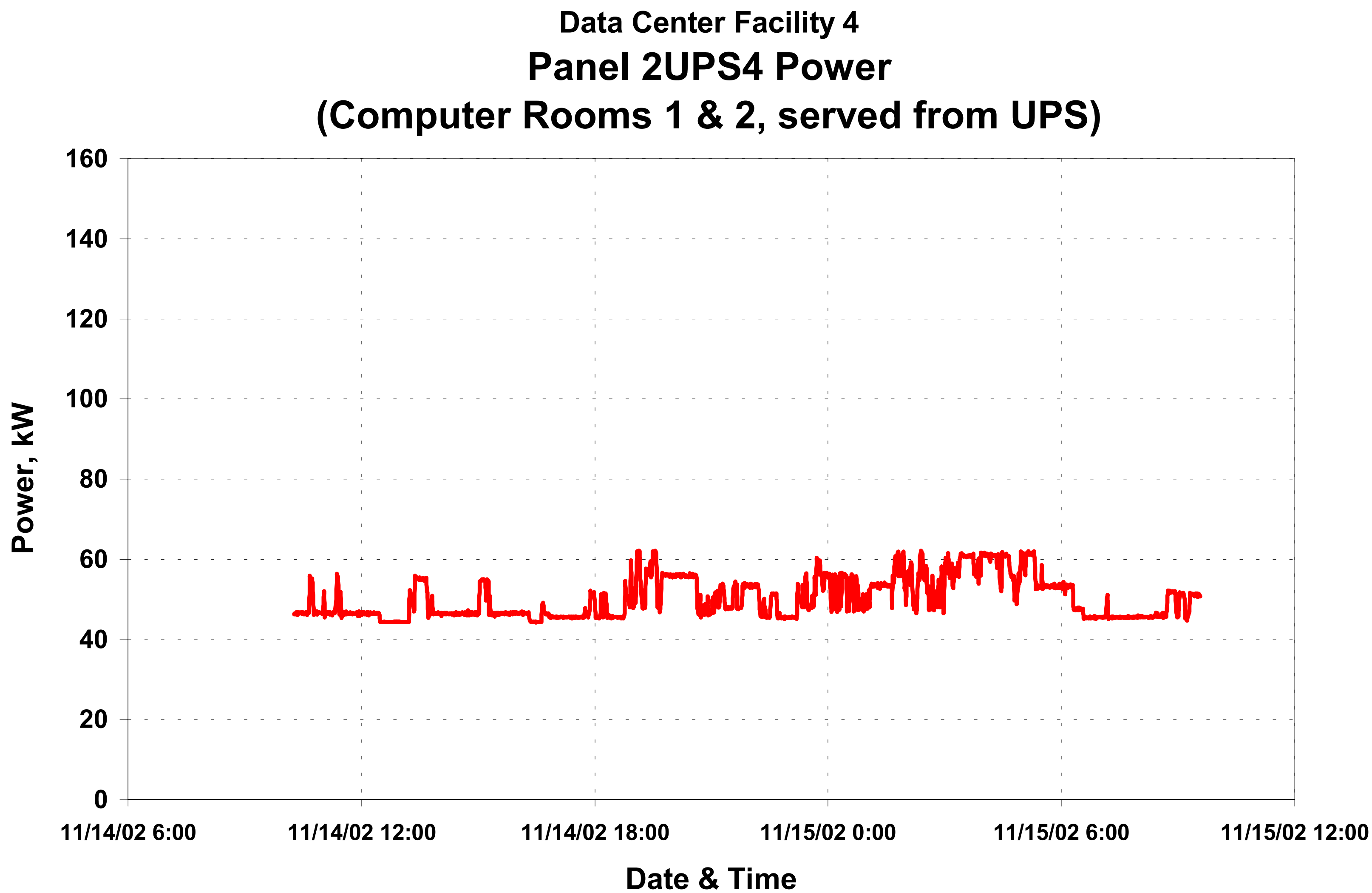
Appendix A

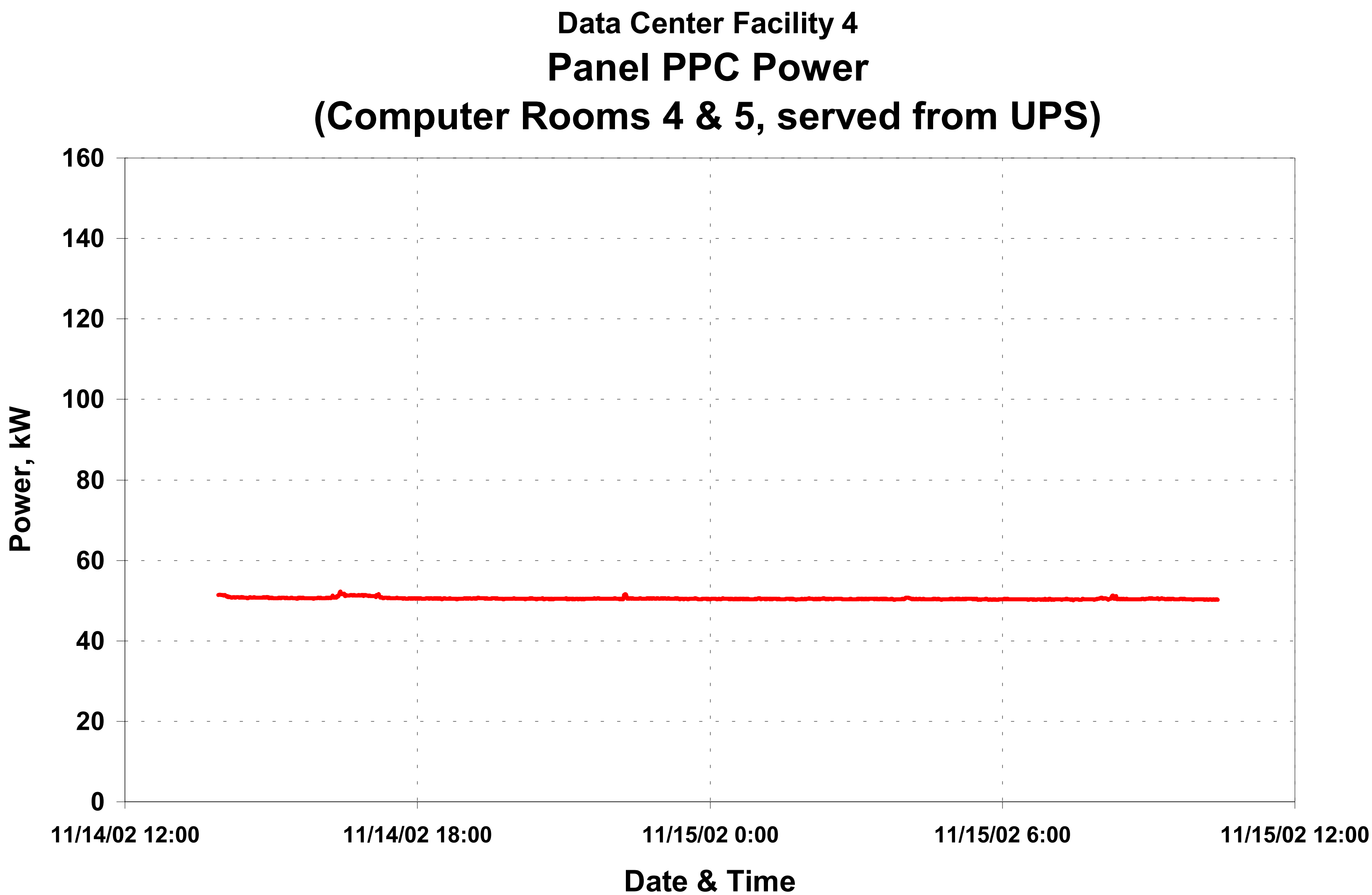
Charts of Measured Data

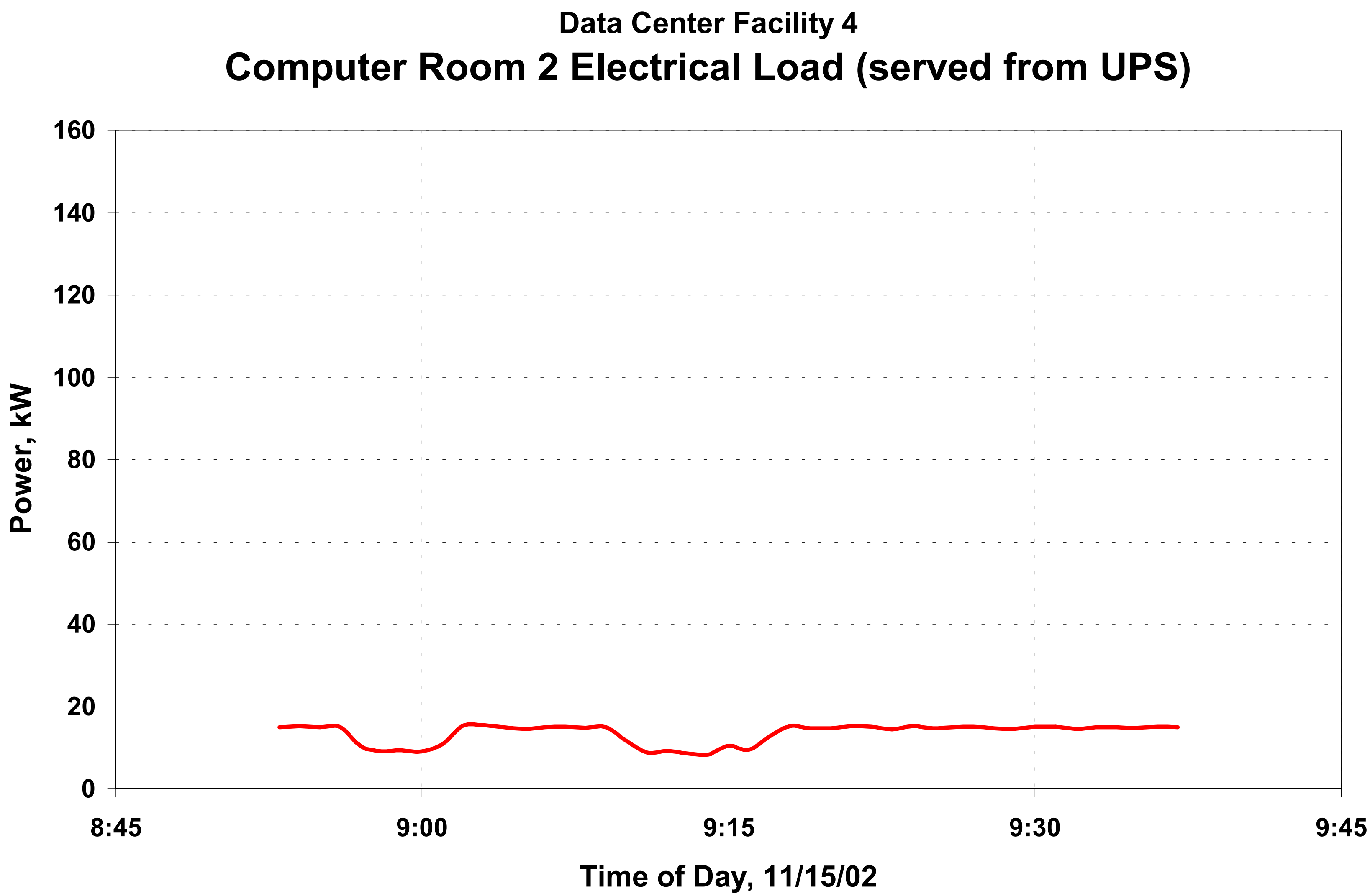


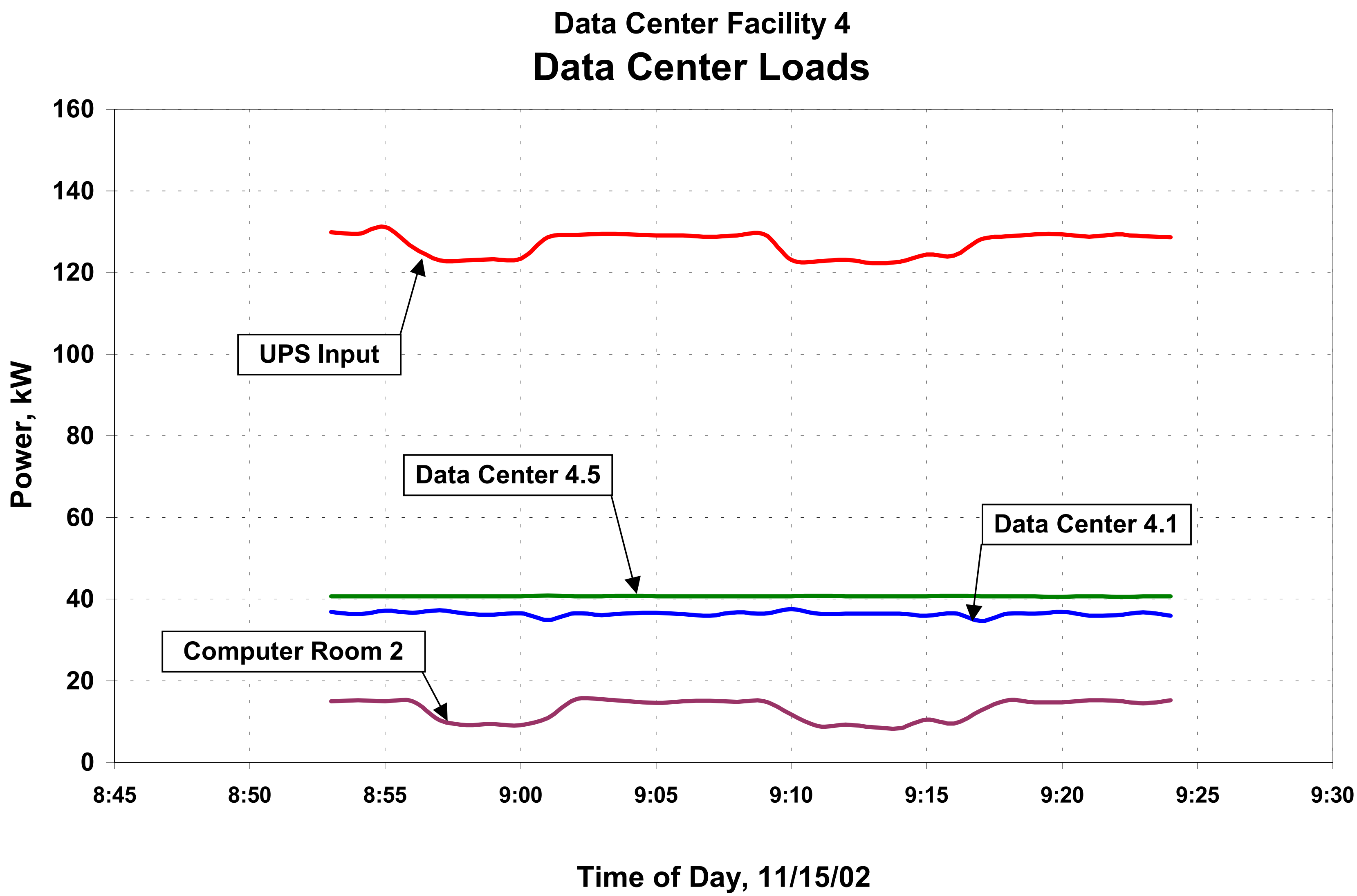
Data Center Facility 4
Outside Air Conditions
Dry Bulb Temperature, °F
Relative Humidity, %
Relative Humidity
Dry Bulb Temperature
120
100
80
60
40
20
0
11/13/02 12:00
11/13/02 18:00
11/14/02 0:00
11/14/02 6:00
11/14/02 12:00
11/14/02 18:00
11/15/02 0:00
11/15/02 6:00
11/15/02 12:00
Date & Time


Data Center Facility 4
UPS Input Power
Power, kW
160
140
120
100
80
60
40
20
0
11/14/02 6:00
11/14/02 12:00
11/14/02 18:00
11/15/02 0:00
11/15/02 6:00
11/15/02 12:00
Date & Time

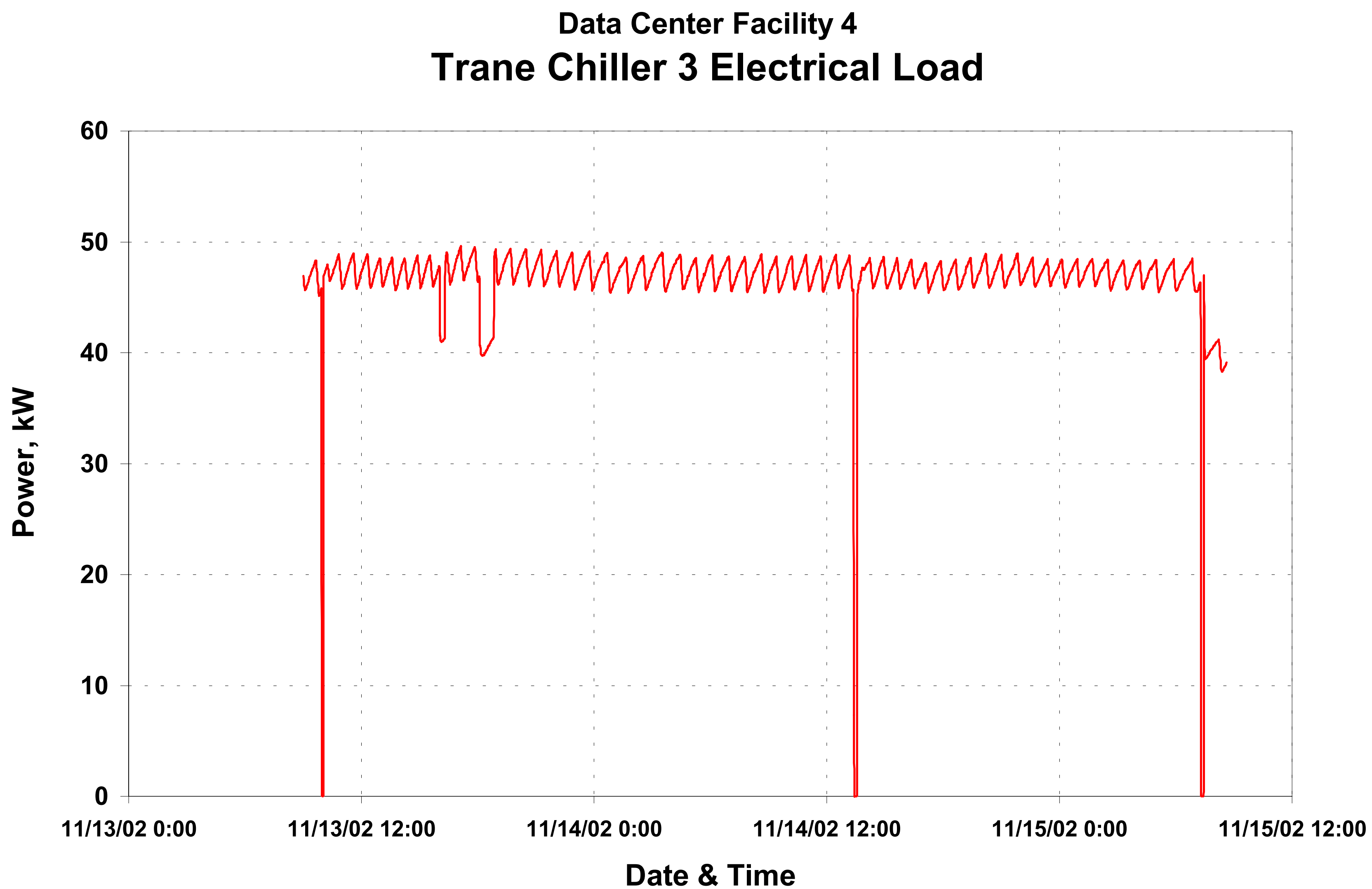

Data Center Facility 4
Panel 2UPS4 Power
(Computer Rooms 1 & 2, served from UPS)
Power, kW
160
140
120
100
80
60
40
20
0
11/14/02 6:00
11/14/02 12:00
11/14/02 18:00
11/15/02 0:00
11/15/02 6:00
11/15/02 12:00
Date & Time

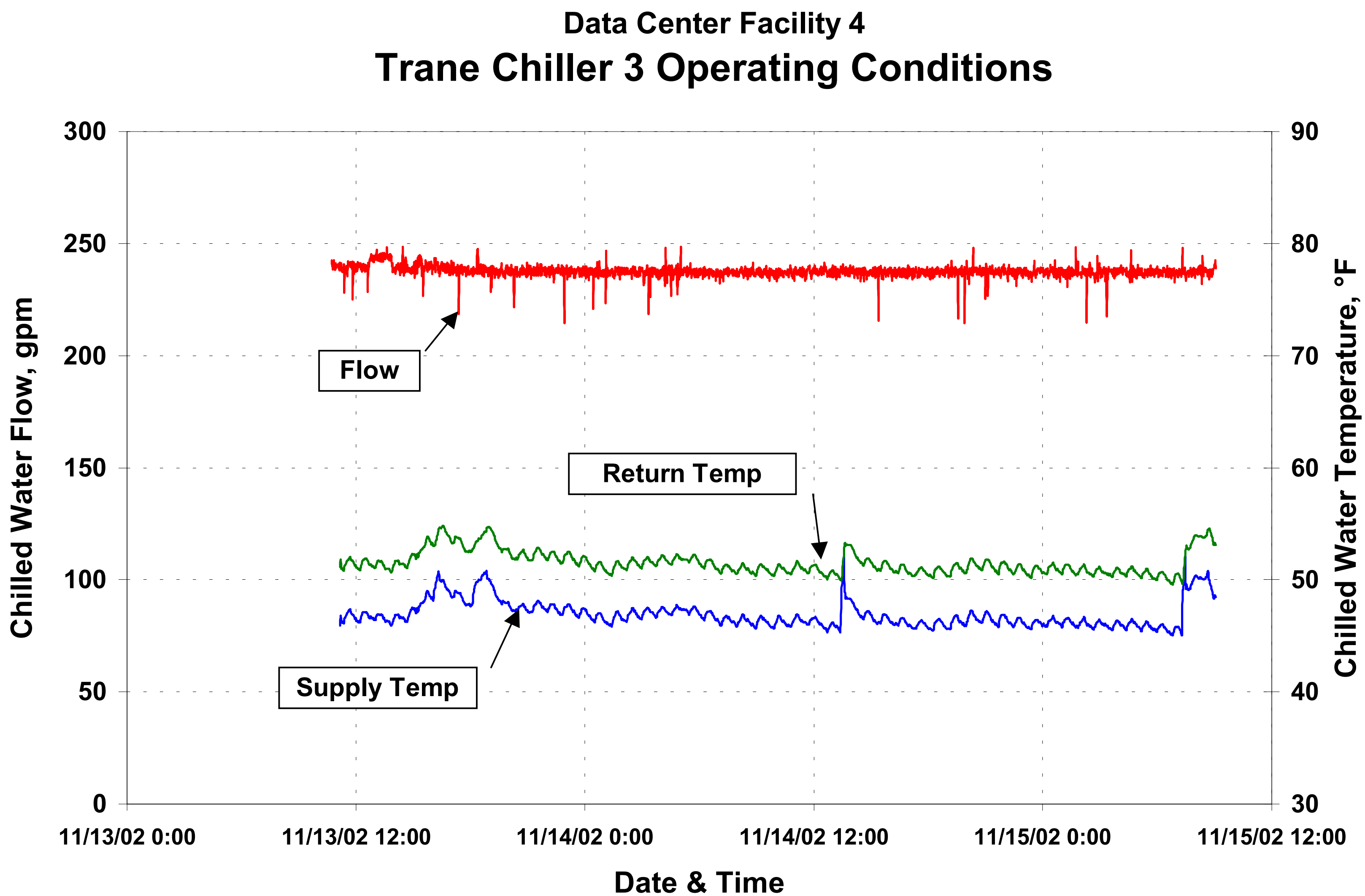

Data Center Facility 4
Panel PPC Power
(Computer Rooms 4 & 5, served from UPS)
Power, kW
160
140
120
100
80
60
40
20
0
11/14/02 12:00
11/14/02 18:00
11/15/02 0:00
11/15/02 6:00
11/15/02 12:00
Date & Time

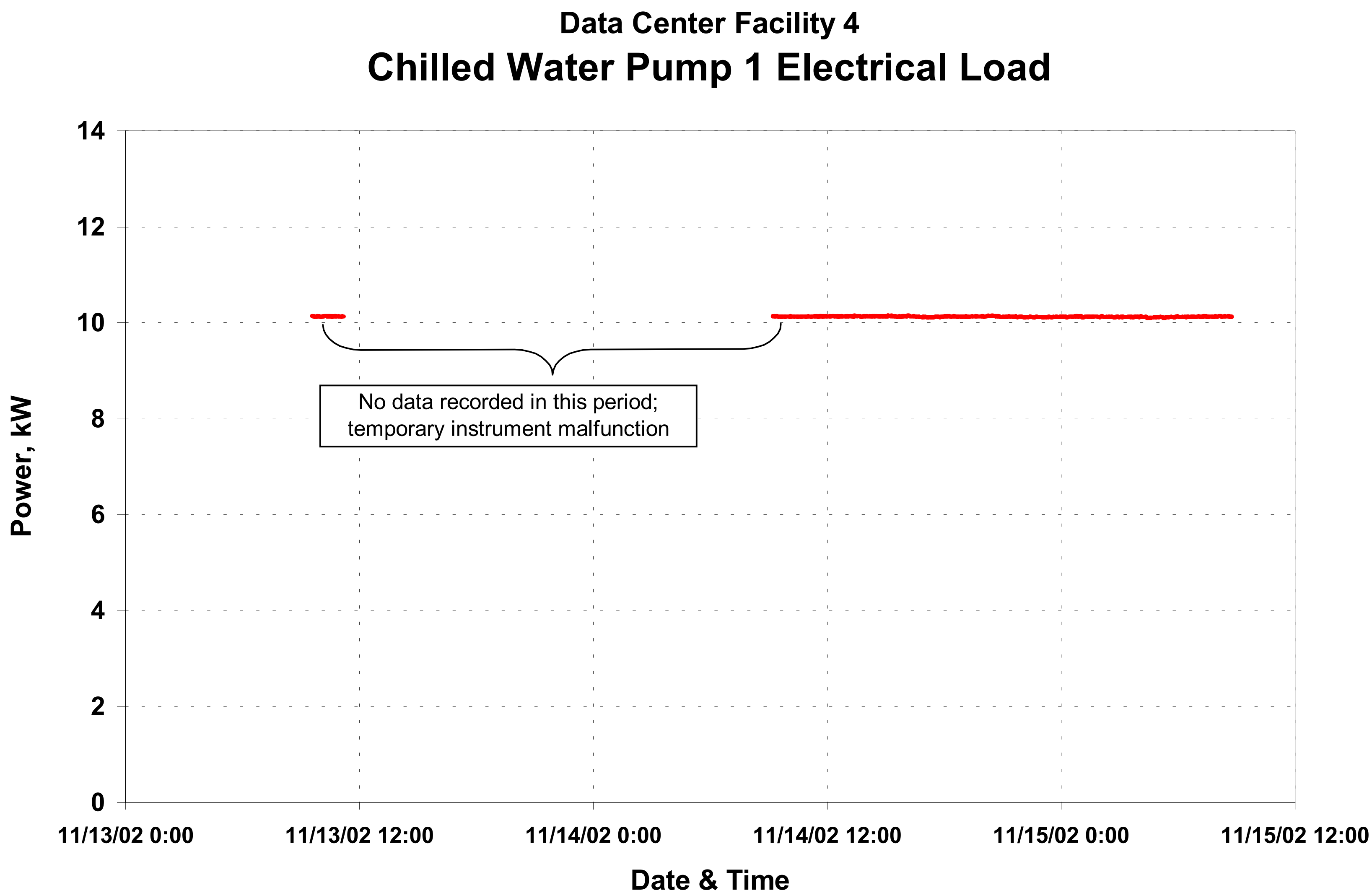

Data Center Facility 4
Computer Room 2 Electrical Load (served from UPS)
Power, kW
160
140
120
100
80
60
40
20
0
8:45
9:00
9:15
9:30
9:45
Time of Day, 11/15/02



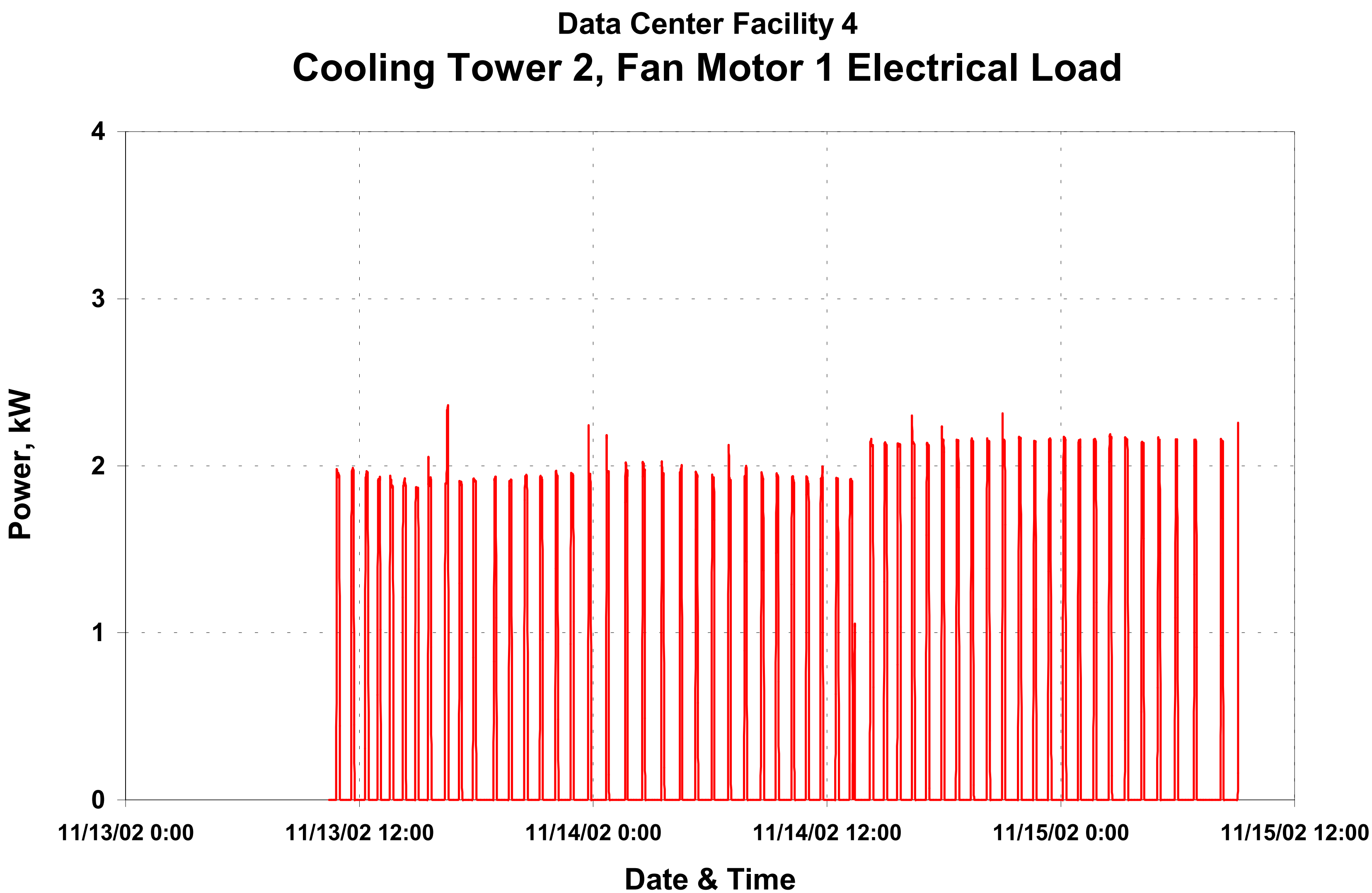
Data Center Facility 4
Data Center Loads
Power, kW
160
140
120
100
80
60
40
20
0
UPS Input
Data Center 4.5
Data Center 4.1
Computer Room 2
8:45
8:50
8:55
9:00
9:05
9:10
9:15
9:20
9:25
9:30
Time of Day, 11/15/02

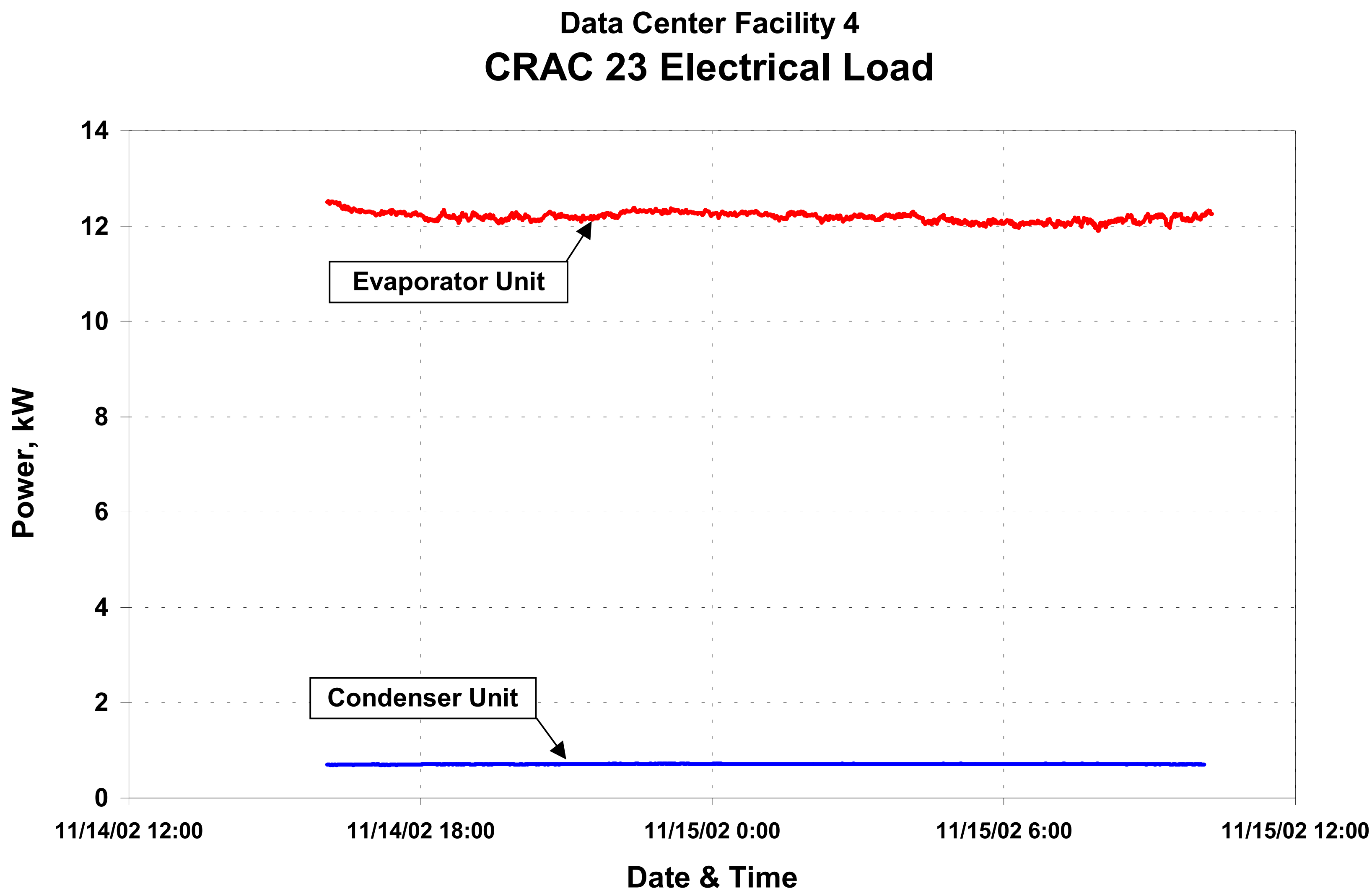

Data Center Facility 4
Trane Chiller 3 Electrical Load
Power, kW
60
50
40
30
20
10
0
11/13/02 0:00
11/13/02 12:00
11/14/02 0:00
11/14/02 12:00
11/15/02 0:00
11/15/02 12:00
Date & Time

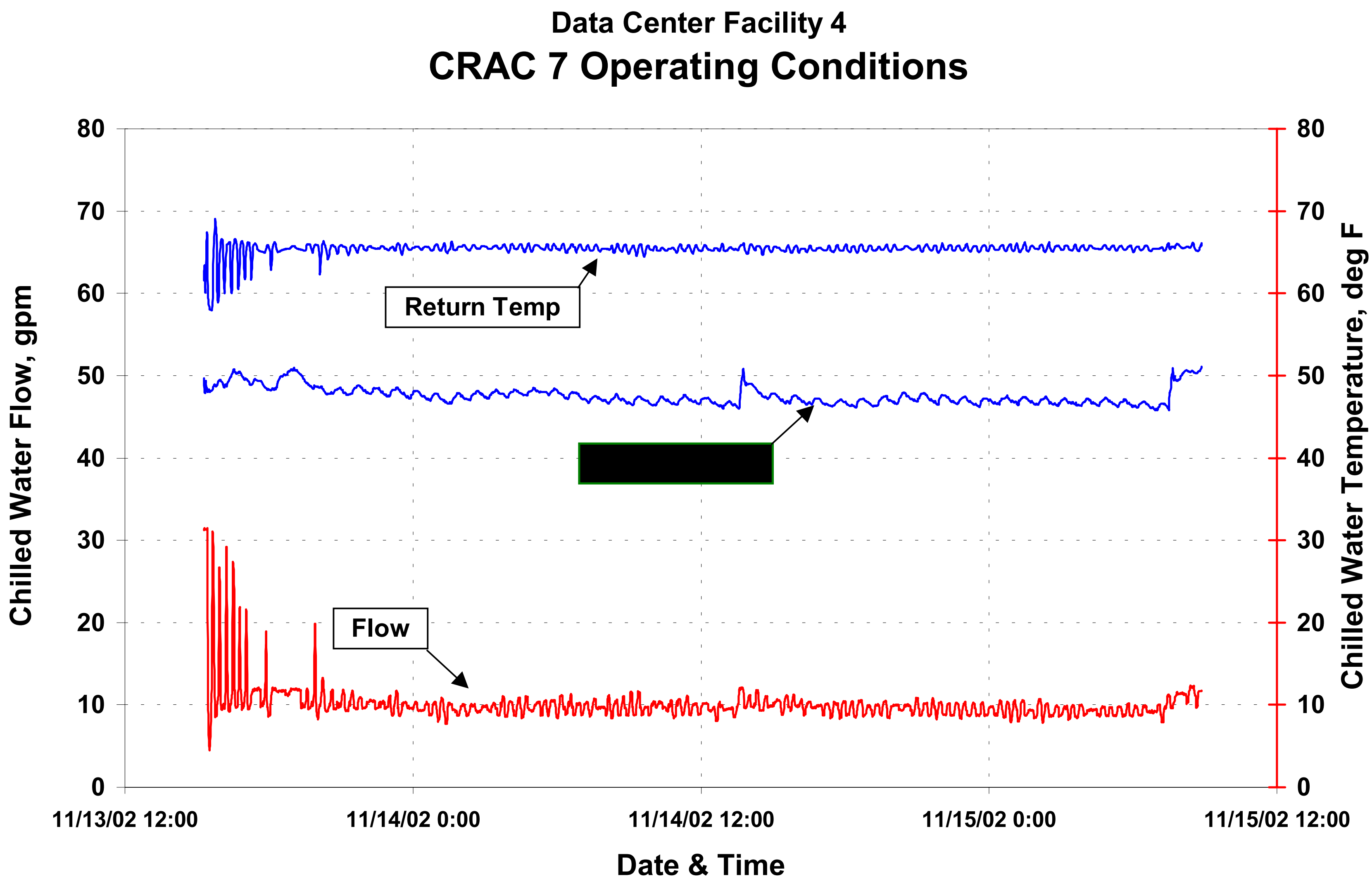

Data Center Facility 4
Trane Chiller 3 Operating Conditions
300
250
200
150
100
50
0
90
80
70
60
50
40
30
Chilled Water Flow, gpm
Chilled Water Temperature, °F
Flow
Return Temp
Supply Temp
11/13/02 0:00
11/13/02 12:00
11/14/02 0:00
11/14/02 12:00
11/15/02 0:00
11/15/02 12:00
Date & Time



Data Center Facility 4
Chilled Water Pump 1 Electrical Load
14
12
10
8
6
4
2
0
Power, kW
No data recorded in this period;
temporary instrument malfunction
11/13/02 0:00
11/13/02 12:00
11/14/02 0:00
11/14/02 12:00
11/15/02 0:00
11/15/02 12:00
Date & Time


Data Center Facility 4
Cooling Tower 2, Fan Motor 1 Electrical Load
Power, kW
0
1
2
3
4
11/13/02 0:00
11/13/02 12:00
11/14/02 0:00
11/14/02 12:00
11/15/02 0:00
11/15/02 12:00
Date & Time


Data Center Facility 4
CRAC 23 Electrical Load
Power, kW
14
12
10
8
6
4
2
0
Evaporator Unit
Condenser Unit
11/14/02 12:00
11/14/02 18:00
11/15/02 0:00
11/15/02 6:00
11/15/02 12:00
Date & Time


Data Center Facility 4
CRAC 7 Operating Conditions
Return Temp
[redacted]
Flow
Chilled Water Flow, gpm
Chilled Water Temperature, deg F
80
70
60
50
40
30
20
10
0
11/13/02 12:00
11/14/02 0:00
11/14/02 12:00
11/15/02 0:00
11/15/02 12:00
Date & Time

Appendix B

Estimate of Data Center Non-Critical Load

Both Data Center 4.1 and Data Center 4.5 contain a variety of computer equipment. The equipment is categorized as follows.

Table B.1. Computer Equipment Categories

Servers	Racks of modular computers, or unitary systems in cabinets.
Terminals	Monitor-and-keyboard interfaces to the servers.
Tape Drives	Desktop unit for backup tapes.
PCs	Standard combination of monitor, keyboard, and stand-alone computer.
Laser Printers	Desktop models.
Dot-matrix printers	Mostly large floor models; some desktop models.

Table B.2. Computer Equipment Count and Operating Status

	Data Center 4.1		Data Center 4.5	
	Count	On	Count	On
Servers	60	60	66	66
Terminals	6	6	4	4
Tape Drives	1	1	0	0
PCs	15	8	25	17
Laser Printers	1	1	3	3
Dot-matrix	0	0	7	7

All servers, terminals, and tape drives are considered critical load. Approximately half of the PCs are critical load and half are not. The printers are not critical load, but they draw very little power in stand-by mode. None of the printers were operating during the period of monitoring. Printer power is not included in the estimate of non-critical loads.

The PCs draw an estimated 100-Watts each. Assuming four PCs in Data Center 4.1 and eight PCs in Data Center 4.5 are non-critical load, which yields 400 W and 800 W for the data center non-critical loads, respectively.

Appendix C

Estimate of Data-Aire CRAC Unit Performance and Efficiency

All specifications are from Data-Aire's brochure; see www.dataaire.com.

Evaporator Unit
Model No. DAAD-2034

The units in Data Center 4.5 were observed to be equipped with hot gas reheat. Otherwise the units are assumed to be standard configuration.

Parameter	Value	Units	Remarks
Nominal cooling capacity	20	tons	--
Total cooling capacity	247,900	BTU/hr	72 deg F DB, 60 deg F WB, 50% RH
Sensible cooling capacity	201,600	BTU/hr	72 deg F DB, 60 deg F WB, 50% RH
No. of fan motors	1	--	--
Fan motor nameplate power	5	hp	Full Load Amps (FLA) = 6.6 amps
Air flow	8,000	cfm	External static pressure = 0.5 in. w.g.
No. of compressors	2	--	Hermetic scroll
Humidifier power	3.3 to 10.2	kW	--

Rooftop Condenser Unit
Model No. DARC-37

The standard condenser for the DAAD-2034 evaporator unit is the DARC-21, but this facility uses the DARC-37 condenser unit instead.

Parameter	Value	Units	Remarks
No. of fans	4	--	--
Fan motor nameplate power	0.75	hp	Single-phase, permanent split capacitor

Estimates
The Data-Aire brochure does not list EER ratings or other efficiency data. A very similar 20-ton CRAC unit made by Compu-Aire (model CAA-20) has an EER of 8.5. This is a reasonable number; the Data-Aire DAAD-2034 is assumed to have the same efficiency.

EER 8.5 = 1.41 kW/ton.

Assume unit is performing sensible cooling only (no dehumidifying).
Assume unit is not humidifying.

Specifications say the unit's sensible cooling capacity is 201,600 BTU/hr = 16.8 tons.

16.8 tons x 1.41 kW/ton = 23.7 kW at full load. This electrical draw includes the condenser unit power.

Each fan motor in the condenser unit is nominally 0.75 hp. Assume the brake horsepower is 80% of that, or 0.60 hp = 0.80 kW. This agrees well with the measured average condenser power of 0.70 kW, assuming only one fan was running. At full load, assume condenser power is 4 fans * 0.80 kW/fan = 3.2 kW.

The CRAC unit fan motor FLA rating is 6.6 amps. Motor full load kW = 6.6 amps x 460 volts x 1.732 = 5.3 kW. Assume the unit is designed so that the motor draws 80% of full load amps, or 4.2 kW. The fan motor is constant speed.

The spot measurement of CRAC 24 power was 4.3 kW. Assume CRAC 24 compressor was not running, only the fan. Assume fans in all CRAC units in Data Center 4.5 draw the same amount of power.

At full load with sensible cooling only, we assume both compressors are running equally. Each compressor draws (23.7 kW – 4.2 kW – 3.2 kW) / 2 = 8.1 kW.

CRAC 23 drew 12.2 kW during the period of monitoring. Subtracting 4.3 kW for the fan leaves 7.9 kW, which corresponds well with 8.1 kW for a single compressor.

If full load sensible cooling is 16.8 tons with two compressors, then one compressor corresponds to 8.4 tons.

If one other CRAC unit was operating similarly to CRAC 23, then the CRAC units were providing 16.8 tons of cooling to Data Center 4.5.

Appendix D

Marley Technical Report: The Application of Cooling Towers for Free Cooling

This report is available on the World Wide Web at
http://www.marleyct.com/pdf_forms/TRH-002.pdf